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ELF Communications System Ecological Monitoring Program: Summary of 1988 Progress

John E. Zapotosky

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A long-term Ecological Monitoring Program is being conducted to monitor for possible effects from the operation of the U.S. Navy's ELF Communications System to resident biota and their ecological relationships. Monitoring studies were selected through a peer reviewed, competitive bidding process in mid-1982, and work on most studies began in late summer of that year. Preliminary activities of the Program consisted of site selection, characterization of critical study aspects, and validation of assumptions made in original proposal. Subsequently, increasing emphasis has been placed on the collection of preoperational and operational data bases at the Michigan and Wisconsin Transmitting Facilities. The data bases are being used to make proposed spatial and/or temporal comparisons of biological and ecological variables. This report summarizes the progress of the Ecological Monitoring Program during 1988.

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FOREWORD

The U.S. Department of the Navy is conducting a long-term program to monitor for possible effects to resident biota and their ecological relationships from the operation of the Navy's Extremely Low Frequency (ELF) Communications System. The program is funded by the Space and Naval Warfare Systems Command through a contract to IIT Research Institute (IITRI). IITRI provides engineering support to the program and coordinates the efforts of ecological study teams. Monitoring projects are being conducted under subcontract arrangements between IITRI and university investigators.

This report summarizes the activities of the ELF Communications System Ecological Monitoring Program during 1988. The information presented was derived from other, more detailed technical reports of ecological findings[1] and electromagnetic exposures.[2] Since the inception of the Program in 1982, IITRI has annually compiled subcontractor reports of efforts and findings,[3-8] documented engineering support activities,[9-13] and summarized the progress of the Program.[14-19] Subcontractor reports have been peer reviewed and all were submitted (unedited by the Navy or IITRI) to the National Technical Information Service for unlimited distribution. Investigators have also related their findings as presentations to scientific societies and as articles in peer-reviewed journals. A listing of presentations and publications is provided as Appendix A.

Respectfully submitted,
IIT RESEARCH INSTITUTE

J. E. Zapotosky, Ph.D.
Program Coordinator

Approved:

R. D. Carlson
Program Manager

A. R. Valentino, Director
Electromagnetics and Electronics Department

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1. INTRODUCTION

1.1 PURPOSE

The purpose of the Ecological Monitoring Program is to determine whether electromagnetic (EM) fields produced by tne Navy's ELF Communications System will affect resident biota or their ecological relationships.

1.2 ELF COMMUNICATIONS SYSTEM

The complete ELF Communications System consists of two transmitting facilities, one located in the Chequamegon National Forest in Wisconsin and the other located in the Copper Country and Escanaba River State Forests in Michigan (see Figure 1). Each facility consists primarily of a transmitter connected by long overhead wires (antenna) to buried ground terminals. Both the antenna and grounding elements are located in cleared rights-of-way (ROW). The transmitters broadcast messages using ELF EM fields; these fields are the operational components of interest.

EM exposure from the ELF Communications System can be conveniently divided into preoperational, transitional, and operational phases. During the preoperational phase, biota received no EM exposure from the ELF Communications System. The transitional phase began with the initiation of system testing; exposures during this phase are intermittent and at lower intensities than intended for an operational ELF system. When the ELF system achieves a full operational capability, EM exposure will be nearly continuous and at full intensity. The Wisconsin Transmitting Facility (WTF) reached fully operational capability during the last quarter of 1985; intermittent operation of the Michigan Transmitting Facility (MTF) was begun in the second quarter of 1986 and continued through 1988.

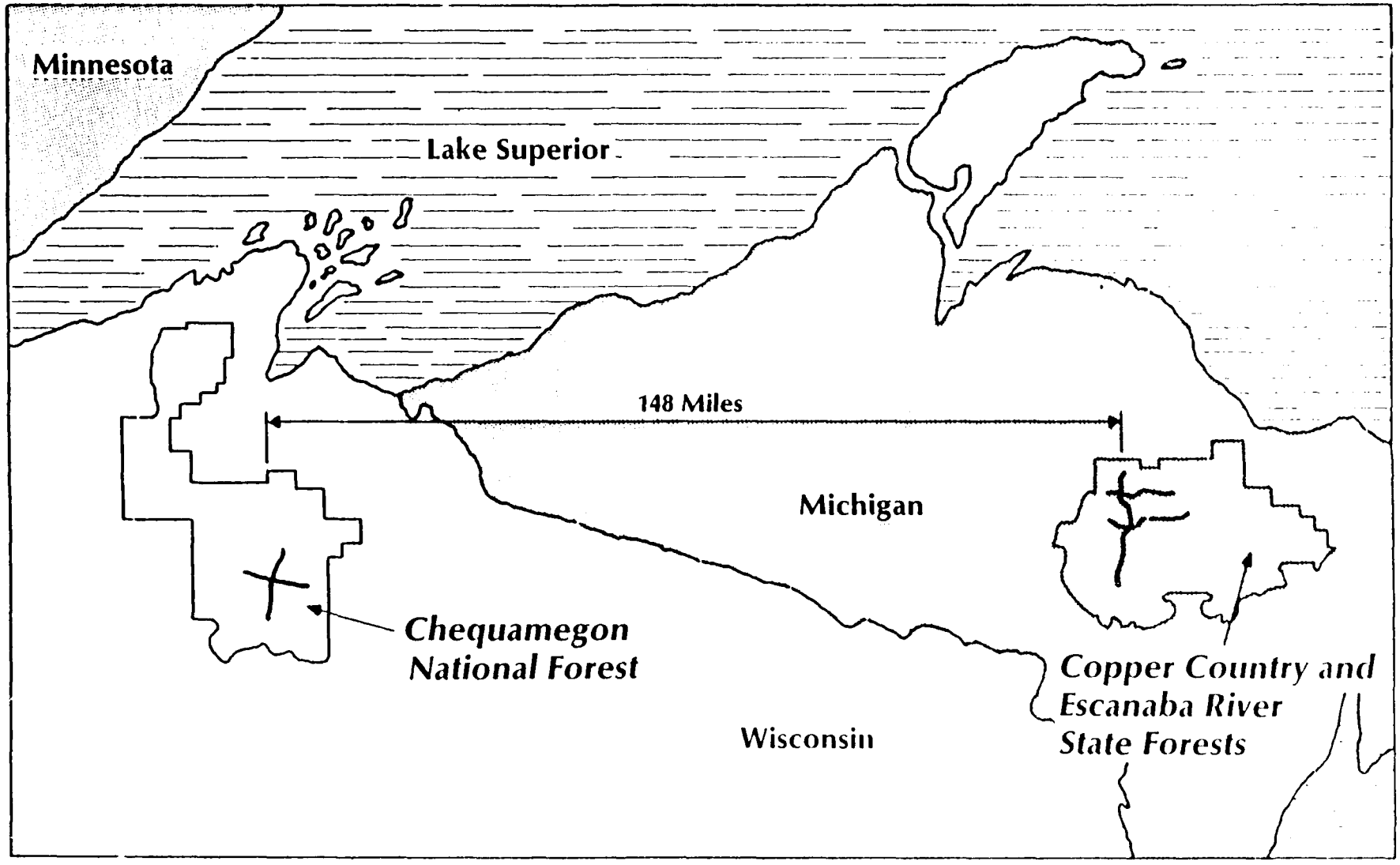

FIGURE 1. ELF COMMUNICATIONS FACILITIES IN WISCONSIN AND MICHIGAN.

1.3 ELF BIOEFFECT EVALUATIONS

Research on possible EM effects to biota from exposure to EM fields produced by an ELF Communications System began in 1969. Although ecological and wildlife studies were performed in the ensuing years, the major emphasis of most ELF System-related research was on laboratory investigations. In 1977, the Navy and the National Academy of Sciences (NAS) examined the information produced by these studies as well as studies performed at other ELF frequencies. Specific research simulating planned operating conditions of the ELF system, as well as research at other ELF frequencies, indicated no acute bioeffects from exposure to ELF EM fields. Those bioeffects reported were minor and/or were controversial among researchers. The Navy and the NAS concluded that adverse effects to biota from the operation of the ELF system were unlikely. After reviewing the pertinent bioelectromagnetic research reported in open literature over the 1977-1984 period, the American Institute of Biological Sciences (AIBS) reached the same conclusion as the Navy and the NAS. Despite the unlikelihood of adverse effects, the Navy, and subsequently the NAS and AIBS, recommended that a program be conducted in the ELF Communications System area to monitor for possible changes to resident biota.

1.4 MONITORING PROGRAM DESIGN

In its 1977 environmental impact statement, the Navy outlined a preliminary plan for conducting such a program at those sites approved for operation of the ELF Communications System. The initial design was developed from the results of laboratory research, input from state agencies, and recommendations made by the Navy and NAS. These elements were later refined based on comments submitted in response to the Navy's draft environmental impact statement. A long-term program of *in-situ* monitoring of biological and ecological variables was planned. Possible effects to pertinent biota were to be examined for by rigorous statistical analyses of spatial and temporal differences.

Study Organisms and Variables. The selection of general types of organisms for monitoring was based on their likelihood of being affected by EM fields and on the basis of their ecological significance. Literature reports of EM effects, even though at higher intensities or at ELF frequencies other

than those employed by the ELF System, were used in the selection process. The organisms' importance to the ecosystems present in the area were also used. Upon completion, the program will have examined 16 general types of organisms dominant in the upland, wetland, and aquatic ecosystems of the ELF Communications System area.

The principal criterion for selecting specific biota was their presence in sufficient numbers to ensure meaningful comparisons. Rare or endangered species have not been examined due to their low population sizes.

The program monitors for possible effects at several levels of biological organization. Organismal studies focus on the characteristics of individuals (e.g., behavior, physiology). Ecological variables address levels of organization more complex than the individual, i.e., populations, communities, and ecosystems. Population variables (e.g., density, fecundity, distribution) are important because they can reflect possible subtle effects to many individuals. Community and ecosystem variables (e.g., diversity, productivity, nutrient cycling) integrate the response of many individuals and species.

An ecological approach has been taken to examine for possible effects to the disparate species present in the area. One limitation of this approach is that ecological characteristics are highly variable, so a substantial effect must be demonstrated in order for researchers to detect it. Although narrower in scope, organismal studies have also been undertaken to provide a more statistically sensitive approach than the ecological studies. Ecological studies also provide a context for evaluating the importance of possible positive findings at the organismal level. Except for one, every project in the program couples organismal studies with monitoring at ecological levels.

Study Sites and EM Exposure. The Monitoring Program employs a paired treatment and control site design to examine for possible effects of ELF EM fields on biological and ecological variables. Treatment sites are positioned close to the overhead wires and grounds of the transmitters, while control sites are located at a distance from these transmitter elements (see Figures 2 and 3). Such sites have essentially matched biotic and abiotic characteristics, but purposely dissimilar ELF EM exposures. Sites have been located so as to insure that the intensity of ELF System-generated EM fields

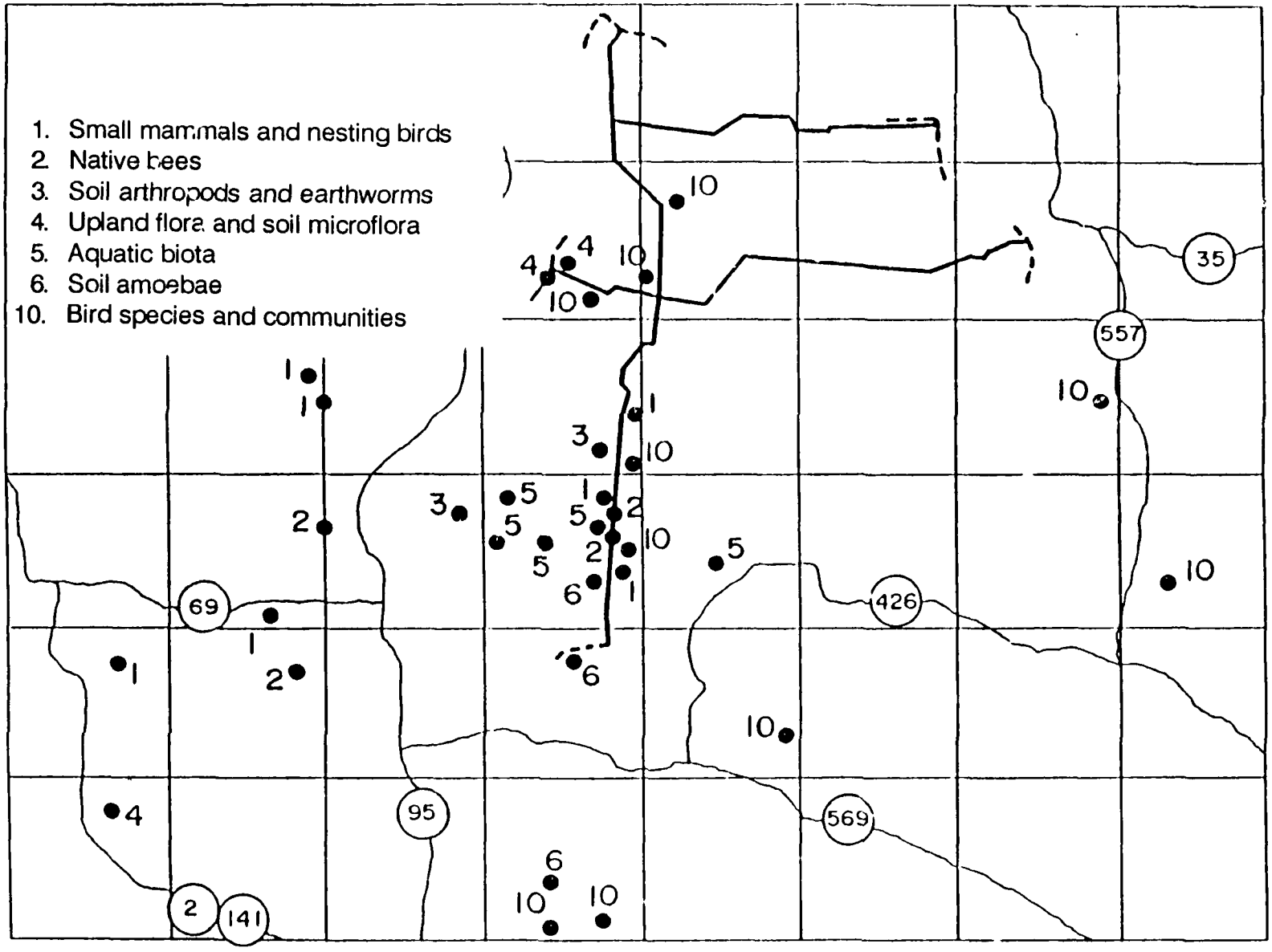

FIGURE 2. FIELD SITES FOR MICHIGAN STUDIES.

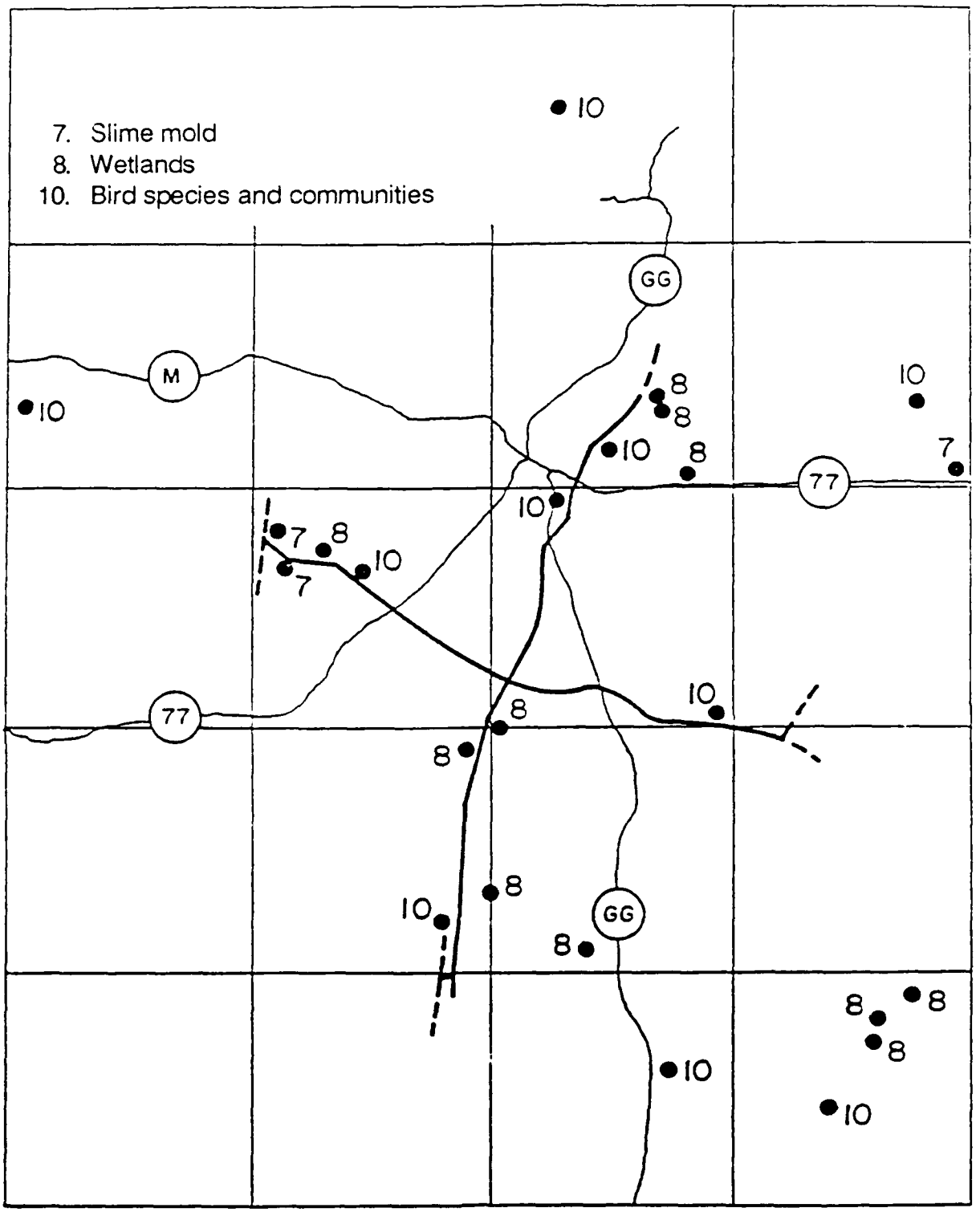

FIGURE 3. FIELD SITES FOR WISCONSIN STUDIES.

at the treatment site are significantly larger than those at the control site. Data collected at the control site represent the effects of natural environmental conditions. While data collected on the treatment sites represent the effects, if any, of natural conditions plus exposure to EM intensities higher than those on the control.

As multiyear studies are being performed, temporal comparison of variables are also possible. Comparison of data collected during preoperational (no EM exposure) to data collected during the intermittent and operational phases of the MTF will be made for Michigan studies. A preoperational data base does not exist for studies in Wisconsin, therefore comparisons are primarily spatial.

Period of Performance. The period of performance for the program had to address several monitoring aspects including: organismal generation times, assessment of an operational ELF Communications System, and non-ELF changes in variables. The actual and proposed schedule for studies in Michigan and Wisconsin are presented in Figures 4 and 5.

Possible subtle EM effects to resident biota would probably not be expressed at the population or community levels for several generations. Long lived animal species, in particular, have life cycles longer than two years. If adults are less susceptible than younger individuals, one would anticipate a time lag until lack of recruitment of young individuals is reflected in processing rates (e.g., decomposition) and/or community composition (e.g., diversity). If ELF EM fields affects the development of the young in such species, possible effects may not be obvious until the third year of monitoring.

Early studies of the ELF Communications System lacked a preoperational data base and were performed while the (then) Wisconsin Test Facility was intermittently operated at less than full power. In order to appropriately examine for possible effects, it is necessary to collect data while the ELF System is in full operational mode. The WTF became fully operational in 1985 and the MTF will become fully operational during 1989.

Another concern of the program is the ability to distinguish non-ELF changes from possible changes caused by the ELF Communications System. Biological and ecological variables are known to undergo natural cyclic

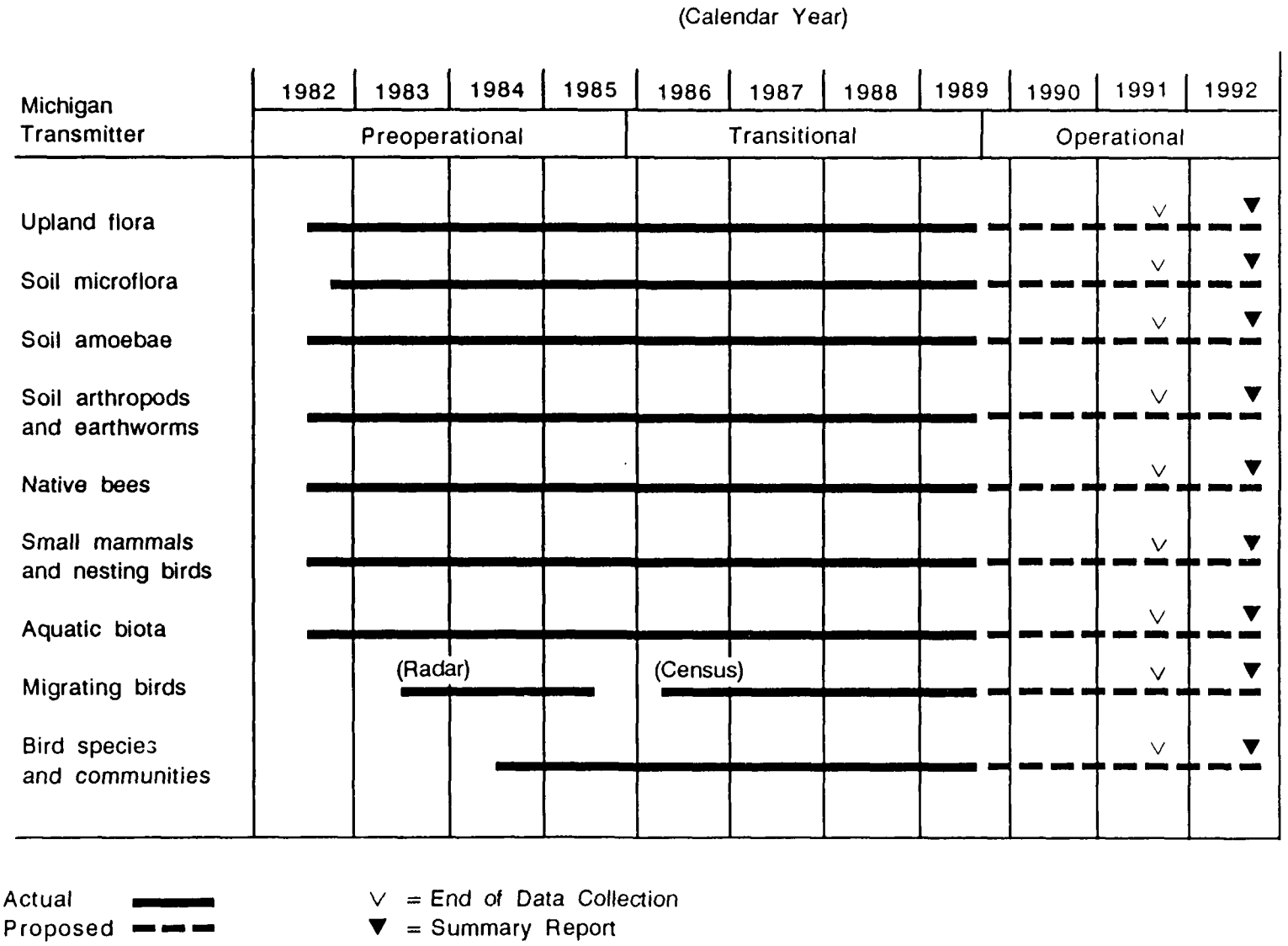

FIGURE 4. SCHEDULE FOR MICHIGAN STUDIES.

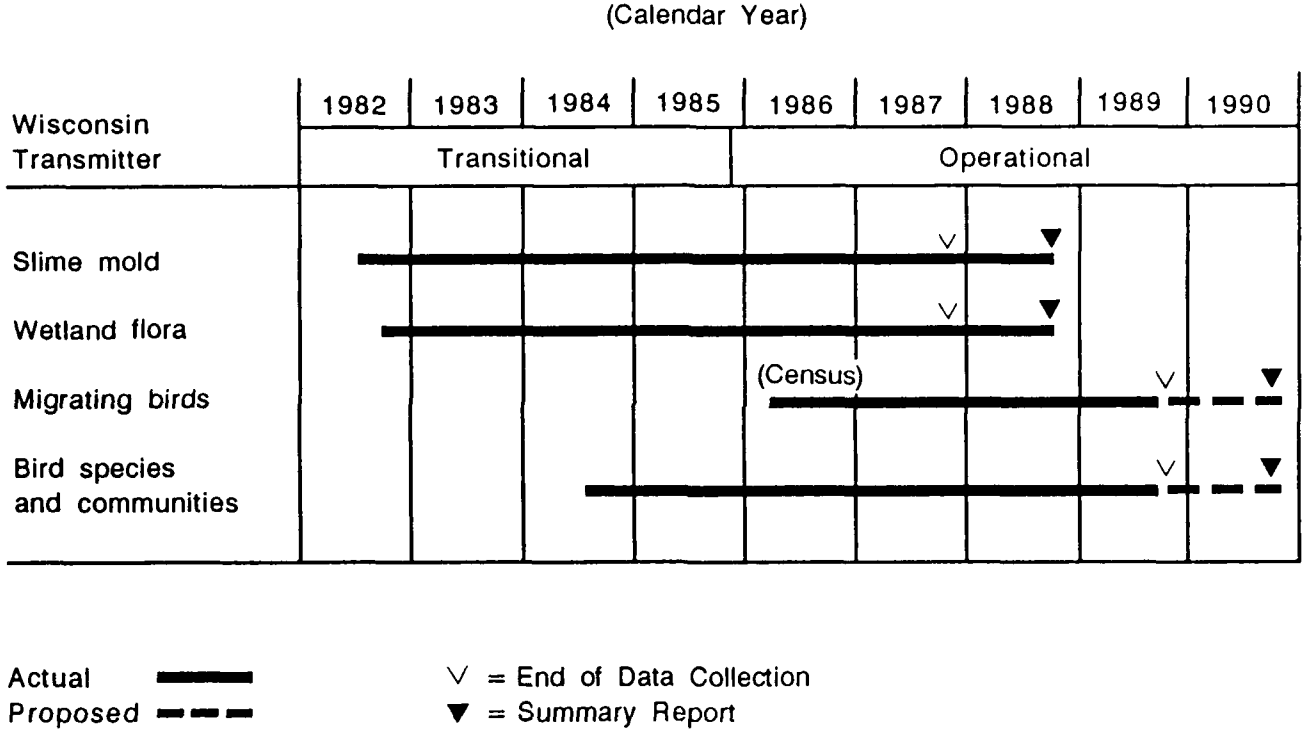

FIGURE 5. SCHEDULE FOR WISCONSIN STUDIES.

changes; they also change in response to anthropogenic factors, such as increased atmosperic CO2. These possibilities are treated, in part, by the treatment and control design aspects of the monitoring program. However, as study sites are separated by large distances, non-ELF factors and site differences may result in different variable responses. Therefore, the period of performance must be of such length as to allow for the collection of sufficient data to address these concerns.

The current schedule provides for three years (1989-1991) of data collection during the operational phase of the MTF and at least three years of data from a preoperational period. During 1986 and 1987, the MTF was operated infrequently and at very low amperage. Many investigators consider data collected during this transitional period, as well as the period prior to 1986, as preoperational. Studies in Wisconsin will have had two to four years (1986-1989) for data collection during the operational phase of the WTF.

1.5 PROGRAM DEVELOPMENT

Concurrently with approval to complete construction of the ELF Communications System, the Department of the Navy funded an Ecological Monitoring Program. Early in 1982, a competitive process was initiated to select subcontractors to participate in the program and by mid-summer preliminary work began for studies of upland flora, soil amoebae, soil arthropods and earthworms, native bees, small mammals and nesting birds, aquatic biota and slime molds. Unsolicited proposals for studies of wetland flora and migrating birds were funded the following year. These latter two studies, plus the eight studies selected in 1982, constituted the program in 1983.

In both 1983 and 1984, peer reviewers expressed serious doubts that the ongoing radar studies of migrating bird disorientation could be used to successfully detect possible effects of the ELF Communications System. The radar study was replaced with a census of migrating birds in 1986.

The major objectives of each study during the early years of the program were the selection of study sites, the validation of assumptions made in the proposals, and the characterization of critical study aspects. These objectives encompassed such activities as:

- identification of biota
- assessment of data collection protocols
- quantification of spatial and temporal patterns for each variable
- assessment of biological and ecological variability

As these tasks were accomplished, increasing emphasis was placed on the collection of data and the refinement of statistical protocols.

In Wisconsin, studies of wetland flora and slime mold have been completed, and a summary report for each provided during 1988. Both studies found some significant differences between sites in the variables examined, however, the significant findings showed no consistent pattern. In several cases significant findings were not supported by additional statistical analyses. Researchers concluded that there were no ELF EM bioeffects on wetland flora nor mold metabolism.

Annual surveys of ruffed grouse, eagle, and deer populations were performed at the WTF by the U.S. Forest Service commencing in 1974, 1975, and 1982, respectively. No effects to these populations from the operation of the ELF Communications System were detected and the studies were concluded after the 1986 surveys.

In Michigan, eight studies continued to collect data and further develop their analytical protocols during 1988. A few studies have sufficient data to statistically perform temporal as well as spatial comparisons. Aquatic studies have shown significant differences in several aquatic variables between the preoperational and transitional phases of the MTF, however there were no corresponding significant differences between sites. The significant temporal differences were attributed to a multiyear drought which started at the same time as intermittent operation of the MTF. Other studies in Michigan have not shown spatial or temporal differences attributable to ELF EM fields.

Bird studies performed in both Wisconsin and Michigan (both preoperational and transitional) have shown some consistent, significant differences between sites for several bird population characteristics. These significant differences have been attributed to differences in habitat on

treatment and control sites. Even though census transects were randomly selected, it was found that there was more coniferous, low-land habitat on treatment transects than on control transects.

2. BIOLOGICAL/ECOLOGICAL STUDIES

This section summarizes the progress for each of the 10 studies that constituted the program during 1988. A more detailed presentation of study protocols, methodology, and progress is given in individual project reports.[1]

The general types of biota being examined are used as subsection titles, while specific study elements are presented as underlined titles in each subsection. In order to simplify presentation of statistical results, any difference described as "significant" had a significance level of 5 percent ($P < 0.05$).

2.1 UPLAND FLORA

Forest vegetation (trees and herbs) is the dominant biota in the ELF Communications System area. The production of organic compounds by vegetation and the subsequent degradation of these compounds comprise the main method of transfer of energy and nutrients to other organisms. Organic matter turnover and distribution are regarded as major determinants of the forest ecosystem's structure. Because the production and distribution of organic matter have been shown to be measurably affected by anthropogenic factors, these processes and associated organisms are being monitored for possible effects from the ELF Communications System. The progress of the upland flora studies is presented here; that of the soil microflora studies is presented in Section 2.2.

In order to examine for possible changes in forest productivity and health, the following elements are being examined:

- growth rates of established tree stands and pine seedlings
- phenological events of trees, herbs, and mycorrhizal fungi
- numbers and kinds of mycorrhizae on red pine seedlings
- nutrient levels of hardwood and pine foliage
- foliage production in hardwoods
- insect damage, disease, and ambient environmental factors.

Treatment sites are located adjacent to the antenna and grounding elements of the MTF. A single control site is located more than 28 miles from the nearest antenna element. The antenna and control sites each consist of overstory tree plots (existing pole-size stands), plots planted with red pine seedlings, and plots of herbaceous plants. The grounding treatment site consists o plots planted with red pine only. No tree stands or herbaceous plots were established at the ELF System grounds because the buffer strips required to eliminate "edge effects" would have placed the study trees at too great a distance from the grounding elements for meaningful EM exposure.

Tree Growth. The purpose of this element is to examine tree growth on both hardwood and red pine tree stands.

Hardwood stands on study sites are classified in the Acer-Quercus-Vaccinium habitat type. Maple, oak, birch, and aspen are the tree species being monitored; all are abundant and common to both the antenna and control sites. Permanently installed dendrometer bands provide continual measurement of diameter growth on each tree in the stand. Bands are read weekly from mid-April until annual growth is nearly complete in early October. At present, five years (1984-1988) of data have been collected.

Differences in the magnitude or timing of seasonal diameter growth of the four tree species are being examined for possible effects from operation of the ELF Communications System. Due to incomplete data for 1984 and pending nutrient analyses for 1988, incremental diameter growth for these two years are not included in the following summary. There were no significant differences between sites or years in the magnitude of diameter change (nor in the timing of diameter growth) when 1985-1987 data were examined using analysis of covariance techniques. Covariates used in the analyses included: air temperature, soil potassium, and water retention capacity of the soil. As the relationships between diameter growth and several covariates are nonlinear, inaccurate results are possible. Therefore, the development of tree growth models continued during 1988.

Young trees experience more rapid rates of growth than older trees, therefore possible effects on growth due to exposure to ELF EM fields is being examined for seedlings (on plantations), as well as older pole-sized trees (on existing stands). At each of three pine plantations, seedlings are

permanently marked for monitoring of total height, basal diameter, terminal bud length, and physical condition. A subsample of the marked seedlings was measured for height on a weekly schedule from April until shoot elongation was complete. The remaining variables were measured on a seasonal basis.

As for the hardwood trees, total annual height and diameter were analyzed through a split plot analysis of covariance, while the pattern of height growth within a season was examined through the use of a height growth model. There were no significant differences between sites or between years (1986-1987) in total annual height growth of red pine. Air temperature, soil nitrogen, and the water holding capacity of the soil were used as covariates in the analyses. There were no significant differences between sites for height growth model coefficients, and except for 1987, there were no significant differences between years.

Analyses of variance without covariates indicated significant differences between sites and between years (1985-1987) in the annual diameter growth of red pine. No covariates were identified that could satisfactorily account for site and year differences in diameter growth, however as there seems to be a time dependent trend, other time-related factors will be examined as covariates. Multiple range tests showed no significant differences in annual diameter growth between ground and control sites in either 1985 or 1986. Diameter growth at both of these sites was significantly different from the growth at the antenna site for the same periods. In 1987, there were no significant differences in diameter growth between antenna and control sites, but the diameter growth at the ground site was significantly different than that at the other sites. Overall, results to date indicate no effect on tree growth by intermittent operation of the MTF.

Mortality of pine due to a fungus disease, first documented in 1986, continued during 1988. Although the percentages are still small, there has been significantly greater mortality on the control site. During 1988, investigators continued to examine possible causal factors for the site differences in pine mortality, so that appropriate covariates can be used in statistical analyses. To date, birch stump frequency has proved to be the most important factor in explaining the distribution of red pine mortality.

Isolates of the fungus *Armillaria* are being cultured to determine the relative success of its clones in killing the pine seedlings.

Phenological Events. Herbaceous plants are an ecologically important component of the habitats found near the MTF. It has been reported in the literature that herbaceous plants will respond to environmental perturbations, and that the timing of some physiological events (e.g., mitosis) in various organisms is altered by exposure to ELF EM fields. The results from monitoring for possible effects from operation of the ELF Communications System on the timing of annual events of herbaceous plants (short-lived) are presented in this section. Possible effects to the phenology of trees (long-lived) are presented in sections dealing with Tree Growth and Litter Production.

The starflower, *Tridentalis borealis*, flowers frequently and is an abundant herb in the ELF Communications System area. Select phenological events, as well as morphological characteristics, of at least 200 naturally growing starflower plants are being followed each year on plots at the antenna and control sites. The onset of flowering and the timing of leaf expansion are the main phenological events being examined. Morphological characteristics being monitored include number of buds, number of flowers, number of fruit and maximal leaf area. In order to precisely delineate periods of flowering and leaf expansion during 1988, these data were collected by making observations at the antenna and control sites twice a week from 2 May through 16 June. Thereafter, observations were made once a week until 25 August.

In 1988, stem expansion on the antenna site began one week earlier than stem expansion on the control site, while leaf expansion occurred at the same time on both sites. Analyses of covariance showed no significant differences between sites in stem expansion (cm/time period), leaf expansion (cm/time period), nor leaf area expansion (cm^2/time period). Similar analyses showed significant differences between years (1985-1988) for stem and area expansions. There were no significant interactions between sites and years for these three variables. The covariates used included: solar radiation, soil temperature, air temperature, and relative humidity. The use of additional climatic factors as covariates failed to explain any of the

significant differences between years. Senescence of leaves (yellowing) began three days earlier on the antenna site, while the occurrence of dead leaves (browning) began at the same time on both sites.

Flowering also began at the same time at both sites. As with bud formation, fruiting occurred one week earlier on the control site than on the antenna site. The proportion of plants flowering in 1988 was significantly lower at both sites than in previous years. Researchers believe that the reduced number of flowers may be related to handling while measuring plant characteristics.

During 1988, possible effects on herbaceous plants from handling were examined. Starflowers outside of the measured transect were randomly chosen, measured, and compared to starflowers in the herbaceous reserve. Results showed that plants on both of the herbaceous reserves were smaller than those outside of the reserve. This phenomenon will be further examined during 1989.

Several morphological characteristics of the starflower were also monitored; leaf area being the primary variable. Using regression analyses, linear equations were fit to observations of leaf area; coefficients (slope and intercepts) were then examined for differences between sites and years. Although there were significant differences between years (1986-1988), there were no significant differences between sites nor were there any significant site/year interactions.

Except for the proportion of plants flowering in 1988, the intersite pattern of phenological events and morphological characteristics of the starflower has remained the same since 1985. To date no effects on herbaceous plants have been discerned from intermittent operation of the MTF.

Herbaceous Plant Cover. This project element was dropped in 1988 due to difficulties in quantification, as well as the low sensitivity of this variable. Documentation of these drawbacks can be found in last year's report.[8]

Mycorrhizal Populations and Root Growth. Mycorrhizal fungi form a symbiotic relationship with the roots of higher plants such as trees. The fungi utilize organic compounds synthesized by the tree for their growth and to "forage" for minerals and water in the soil. In turn, the fungi provide

the tree with minerals and water more efficiently that the tree's roots alone. This relationship is considered essential to the satisfactory growth of nearly all tree species. Because the growth of fungal mycelia are dependent on physiologically produced intracellular electrical currents, other sources of electrical current, such as the ELF Communications System, may have an effect on the fungi and, indirectly, on trees. The population dynamics of mycorrhizae occurring on hardwood and pine trees are being examined.

Data on hardwood mycorrhizae were not collected during 1988 so that the sampling effort could be redirected into expanded studies of *Armillaria*-caused mortality of red pine. However, statistical analysis of hardwood mycorrhizae data collected over the 1984-1987 period continued during 1988.

At plantation sites, the population dynamics of red pine mycorrhizae continued during 1988. Populations are being characterized by the frequency of occurrence of mycorrhizal types and the number of mycorrhizal root tips per red pine seedling. Due to the increase in the size of seedlings and increased numbers of mycorrhizae, a subsampling method was tested in 1986 and implemented in 1987. Mycorrhizae per gram of root weight continues to be the parameter examined, but its basis is lateral root weight rather than total root weight.

In 1988 as in previous years, type 3 was the most common, and type 5 the second most common, mycorrhizae on the roots of the pine seedlings. Type 6, the least common mycorrhizae, are being encountered more regularly. Fewer total mycorrhizae were counted per gram of root in 1988 than in prior years.

Multiple analysis of variance and covariance of all data collected over the 1985-1988 period show no significant differences between sites or years by site in mycorrhizae per unit weight of red pine seedling root. Four temperature covariates were used in the covariate analyses. The covariate that decreased the site and yearly significance levels the most was the number of days with precipitation events greater than 0.10 cm. An overall difference of 10 to 15 percent will be necessary to recognize a significant difference between sites, while an overall difference of 15 to 25 percent will be required to identify a significant difference between years by site.

Litter Production and Foliar Nutrients. The purpose of this element is to examine total litter weight, litter nutrient content, and the nutrient content of oak foliage during the growing season. Total litter weight and litter nutrients provide estimates of seasonal canopy production as well as an estimate of input to the decomposition system (see Section 2.2). A determination of foliar nutrient content makes possible the detection of changes in physiological processes of trees such as nutrient translocation.

Litter is collected in traps on existing hardwood stands at the antenna and control sites. The litter is dried, sorted, and weighed according to the following components: foliage, wood, and miscellaneous. A subsample is taken to determine the nutrient content of the litter. In addition, foliage samples are periodically taken from the crowns of red oak trees for determination of their nutrient content. Pine needles are also collected for nutrient analyses from seedlings growing on pine plantations.

In 1988, major litter fall began at the hardwood sites shortly after 21 September and the fall was complete by 3 November. Litter fall began at a similar time as previous years but had the latest ending of any year monitored since 1984. Except for the miscellaneous category, analysis of covariance showed no significant differences between sites or years (1984-1988) for the total weight of the foliage and wood components of the litter. The total weight of the miscellaneous litter category showed a significant difference between years but not between sites. Soil and air temperature were used as covariates. The detection limits for interyear and intersite differences in total foliage weights (10 to 19 percent of the mean) has proven to be more sensitive than the wood (28 to 56 percent) or miscellaneous (33 to 62 percent) components of the litter.

Except for calcium, covariate analyses showed no significant differences between years or sites in the nutrient content of the litter categories. There were significant differences between years in leaf calcium content, however there were no similar differences between sites nor between years for the other components. Covariate analyses of leaf nutrient content by species showed several significant differences between years. These included: phosphorous and magnesium in oak, and calcium in birch. There were no other significant differences between sites or years in the other nutrients for oak

and birch. There were no significant differences between sites or years for the nutrient content of aspen or maple leaves. Covariates used in the analyses included: air temperature, soil temperature, and soil nutrients. Minimum detection levels for litter nutrient content by component or by tree species ranged from 2 to 25 percent of the mean. Significant differences were further examined to determine if nutrient content had changed in response to MTF operation. Multiple range tests using covariate adjusted means showed some of the differences between sites existed before initiation of intermittent operation of the MTF.

In addition to litter, actively photosynthesizing red oak and pine foliage was examined for its nutrient content. Covariate analysis of data collected over the period 1985-1987, showed significant differences between sites in the potassium content of oak foliage. There were no other site differences for four other nutrients. There were significant differences between years in the foliar content for four of five nutrients. Multiple range tests showed that in all cases, significant year and site differences occurred prior to intermittent operation of the MTF. Covariates included air temperature, soil temperature, and soil nutrients. Minimum detection levels for differences in the nutrient content of red oak foliage ranged from 4 to 24 percent of the mean.

Analyses with and without covariates show no significant differences between sites or years in the nutrient content of red pine needles. All foliar nutrient concentrations are above or near levels required for adequate growth. Mycorrhizae per gram of root weight and soil nutrients were used as covariates in the statistical analyses. Examination of other site and ambient factors are planned and minimum detection levels for differences will be calculated following examination of additional covariates.

Results to date indicate that intermittent operation of the MTF has had no detectable effects on tree litter production, the nutrient content of litter nor the nutrient content of actively photosynthesizing foliage.

2.2 SOIL MICROFLORA

Soil microflora (bacteria and fungi) play a key role in the maintenance of upland forest ecosystems such as those in the ELF Communications System area. Microflora decompose organic matter produced by forest vegetation (litter) and fix elements present in the atmosphere into a form available for plant uptake. Anthropogenic factors that disrupt these processes may directly alter the flow of nutrients to vegetation and thus indirectly affect the forest community.

The objective of this element is to monitor for possible effects from EM fields produced by the ELF Communications System on populations of streptomycete bacteria associated with plant roots (mychorrhizae) and rates of decomposition of litter. These objectives are closely related to the upland flora studies (particularly, the mycorrhizal and litter production objectives) described in Section 2.1.

Upland flora (producers) and soil microflora (decomposers) form a natural assemblage; however, these groups are being examined by separate subcontractors. Both subcontractors are with the Department of Forestry, Michigan Technological University, and both share common study sites and ambient monitoring systems.

Streptomycete Bacteria. The purpose of this element is to characterize and enumerate streptomycete bacteria associated with red pine mycorrhizae (see Section 2.1). Streptomycetes have been reported to be involved in the nutrition of mycorrhizae and may influence mycorrhizae through their production of antibiotics or growth factors.

Sample sizes and protocols in 1988 were the same as in previous years. Samples were taken monthly from May through October from pine plantations at the antenna, ground, and control sites. Plate count data were transformed prior to analyses of variance.

Two-way analysis of variance was used to compare sampling dates and study sites within 1988. Three-way analysis of variance was used to compare years (1985-1988), as well as sites and sampling dates. Whenever these analyses showed significant differences, Tukey's H.S.D. procedure was used to conduct multiple comparisons. Covariates, particularly weather-related variables,

were also used to further examine differences between sites, years, or sampling dates.

In 1988, as in all previous years, there were no significant differences between sites in the number of streptomycete morphotypes. Except for a late season peak, the number of morphotypes were not significantly different between sampling dates throughout the 1988 season. During the 1985-1987 period, the seasonal pattern was one of more morphotypes early in the season than later in the season. B and F continue to be the most commonly isolated morphotypes.

Analysis of variance showed significant differences between years (1985-1988) in the number of morphotypes isolated. Detectable difference levels for the four year data base of morphotype numbers were estimated as being between three and six percent. The number of morphotypes present at the study sites has declined annually from 1985 through 1987, while the number of morphotypes isolated in 1988 were about the same as the previous year. Analyses of covariance explained yearly differences when soil temperature, precipitation frequency and total precipitation were used as covariates.

As in the past, there were no significant differences between sites in the numbers of streptomycetes present during 1988. There were, however, significant differences between 1988 sampling dates in the number of streptomycetes isolated. Tukey's multiple comparison tests indicated that October population levels were significantly lower that those of any other month and that May levels were lower that those of July through September.

Analysis of variance also showed significant differences between years. Population levels were significantly higher during 1988 and 1987 than those for 1986 and 1985. Estimated detectable differences (using analysis of variance) were one percent of the mean. As for the numbers of morphotypes, preliminary analysis of covariance explained interyear differences when air temperature degree days, total precipitation and precipitation frequency were used as covariates.

Similar, relatively stable streptomycete populations have become established at all three study sites. Over half of the morphotypes isolated have the ability to degrade cellulose and lignocellulose. Based on data collected since 1985, intersite comparisons appear warranted. Continued

examination of covariates using analysis of covariance will help to identify those environmental factors responsible for interyear differences.

Litter Decomposition and Nutrient Content. The purpose of this element is to determine the rate of decomposition of the litter of three species of trees (oak, maple, and pine) that are abundant in the ELF Communications System area. This variable is being used as an indicator of the overall functioning of the litter community. The original approach of using nutrient fluxes as independent decomposition variables was changed in 1988 and the nutrient content of litter will now be used as covariates in analyses of dry matter loss.

Litter is collected each autumn from a single location, weighed, and then either analyzed for nutrient content or enclosed in nylon mesh envelopes for emplacement at study sites. Envelopes contain either individual leaves or bulk foliage samples of a single species. Samples are emplaced at study sites in December and are retrieved monthly from April through November of the following year. Data are expressed as the percentage of original dry matter mass remaining at the time of retrieval.

Dry matter mass loss data from 1985 through 1988 is complete. Nutrient data for litter collected during 1984-1986 and alternate months in 1987 are also complete. Chemical analysis of litter collected during 1988 is pending.

Statistical analyses of litter was essentially the same as used to examine steptomycete populations, i.e., data were examined by analysis of variance and analysis of covariance for differences between sites and between years. Correlation analysis showed strong relationships between mass loss and the following independent variables:

- weather (temperature and rainfall)
- initial leaf density
- foliar nutrient content.

These independent variables were used alone or in various combinations for analyses of covariance.

Analysis of variance showed many significant differences between hardwood stands (2) and between plantation sites (3). However, covariate analyses showed no significant differences between stands and between plantations in

the mass loss of bulk and individual samples of oak and bulk samples of maple litter. Samples of individual maple leaves are not being examined as the results have been shown to be extremely variable due to the loss of fragments from litter bags. Preliminary analyses of covariance have failed to explain differences between stands and between plantations for individual pine fascicles or bulk pine samples.

There was no clear pattern between years for the decomposition of bulk and individual samples (all three species) emplaced on pine plantations. Generally, mass loss in bulk and individual samples emplaced on hardwood stands was significantly faster in 1985 than any other year (1986-1988). Preliminary analyses indicate that the frequency of precipitation may be useful in explaining differences in mass loss between years.

Many of the significant differences detected can, in part, be attributed to very low variability of the data. Coefficients of variability for 1988 decomposition data were between 2 and 12 percent, with the majority of the coefficients in the lower end of this range. Although they are statistically significant, the small differences between the means of some parameters may not be biologically significant.

2.3 SLIME MOLD

The purpose of this study was to determine whether select physiological variables of the slime mold, *Physarum polycephalum*, were affected by exposure to EM fields produced by the ELF Communications System.

Previous research by the principal investigators (1972-1978) indicated that laboratory simulations of EM field exposures expected from operation of (then) Project Sanguine depressed the rate of respiration and lengthened the mitotic cycle of the slime mold. Over the period 1982-1988, the same investigators examined these two physiological variables plus adenosine triphosphate (ATP) content to determine whether effects occurred when the mold was exposed to both EM fields and environmental conditions present at an operational ELF Communications System facility.

Molds were exposed *in situ* to EM fields present at the WTF and to simulated WTF EM fields in a laboratory. The collection of data was completed in 1987. During 1988, researchers evaluated and analyzed data collected since 1982. They decided that recent data (1985-1987) on respiration rates and ATP content was the most reliable and subjected these data to more rigorous statistical analysis than had previously been performed. Neither the *in situ* nor laboratory data demonstrated a consistently significant EM effect on the mold's respiration rate or ATP content. Examination of the mold's mitotic cycle was abandoned after 1985 due to the ambiguous nature of the results. The following outlines the protocols used and results obtained from EM exposure on the mold's respiration rate and ATP content.

In Situ Studies. *In situ* studies were performed at three WTF sites: two treatment sites located adjacent to either a grounding (G) or an aerial (A) antenna element, and one control site (C) located about seven miles from the nearest ELF System element. The EM fields at the treatment sites were predominantly those produced by the WTF and in all cases were over 100 times greater than the EM fields at the control site.

These studies employed culture chambers that isolated the mold from other soil organisms. As the magnetic flux density is perturbed by neither the culture chambers nor the surrounding earth, the mold's magnetic field exposure was the the same as ambient. However, ambient electrical fields and currents in the soil had to be collected by buried electrodes and supplied to the chambers. At each site, two mold cultures were exposed to electric fields matched to ambient soil intensities (E) while another mold culture was exposed to ambient electric current densities (J). Temporal changes in mold physiology were found to be independent of the type (E or J) of exposure received.

The temperature of the cultures was estimated by one battery-operated monitor located at each site. Physiological changes associated with temperature changes were addressed by plotting a regression line of temperature and then using the residual variance in subsequent statistical analyses.

The molds were grown on an agar substrate within the culture chambers. The macroplasmodia in each culture chamber was subsampled on a weekly basis. One portion of each macroplasmodia was used to start a new culture for continued EM exposure at the WTF under the same regime as the parent. The remaining portion of each macroplasmodia was taken to a laboratory located at the University of Wisconsin-Parkside (UWP), Kenosha, Wisconsin. In the laboratory the macroplasmodia were transformed into microplasmodia; placed into liquid culture; and then, aliquots of the liquid culture were analyzed for ATP content and respiration rate. In order to normalize the data, the protein content of each aliquot sample was also analyzed. Respiration rate was reported as oxygen consumed per minute per mg protein, and ATP was reported as nM ATP per mg protein.

Once the liquid cultures reached vigorous growth in the laboratory, an aliquot from each site (G, A, and C) was placed on agar growth media. These were used as replacement cultures, in the event that a corresponding *in situ* culture was found to be contaminated with other biota.

Using analysis of variance techniques, investigators found that the length of time a culture was out of the EM field affected both the respiration rate and ATP variables. These analyses showed that the respiration rate of the mold was affected more than their ATP content. In 1987, steps were taken to reduce and standardize the length of time out of the EM field for those cultures transported from the WTF.

Laboratory Studies. These studies were performed in treatment and control incubators at the UWP laboratory. Macroplasmodial cultures in treatment incubators received either an electric field (E) or current density (J) similar to that present at the WTF ground site (G). Both cultures were also exposed to the same magnetic flux density (also that present at the G site).

In situ temperatures were simulated by adjusting the treatment and control incubators to the mean daily temperature measured at the G site during the previous week.

In the laboratory, macroplasmodia were grown on the same medium, and in the same culture chambers, as the *in situ* studies. Protocols for the analysis of respiration rate and ATP content of the laboratory-grown plasmodia were

also the same as those used for the *in situ* studies. Backup cultures were not used in the laboratory studies.

Data Analysis. Laboratory data taken during 1987 were analyzed using analysis of variance techniques. Two analyses were performed. One examined for the effects of replicating dependent variable measurements as well as for changes due to the length of time out of the exposure regime. The other examined for the effects of EM intensity and duration of the exposure.

Results indicated that the effects of replications were negligible, however the time out of EM exposure showed a significant interaction with EM intensity. Therefore, only those values from the first set of biological measurements were used in statistical analyses for possible effects of EM intensity and duration. All data from 1985 and 1986 were then reanalysed, using only first measurement values.

In order to correct for possible temperature effects on the biological variables of cultures exposed at the WTF, a linear regression procedure evaluating the relationship of ATP content and respiration rate to mean weekly temperatures was performed. The residuals from this regression were used in subsequent analyses to control for temperature effects. Both analysis of variance and linear regression statistical procedures were used to examine for possible EM effects.

Results. The respiration rate and ATP content of macroplasmodia cultured in the laboratory during 1987 were significantly related to the duration of exposure but they were not significantly related to EM intensity. Changes in the biological variables over time did not follow any pattern, indicating that significant fluctuations occurred in all cultures over time. Other analyses of variance for 1985, 1986 and 1987 laboratory data showed no significant differences between treatment and controls.

The respiration rate and ATP content for plasmodia cultured at the WTF during 1987 were also significantly related to the duration of exposure but not to EM intensity. As in the laboratory, changes in the biological variables over time did not follow any pattern. Other analyses using regression techniques, found only one significant relationship (of 6 possible) between exposure variables and biological variables. In these latter analyses, only the duration of exposure showed a significant relationship to

respiration rate. As temperature and weeks of exposure are highly collinear and both show a significant correlation to respiration, it is difficult to separate the influence of duration of exposure from temperature.

A reanalysis of 1985 and 1986 data, using the same approach as used for the 1987 data, showed biological variables to be significantly related to both intensity and duration of exposure. Nevertheless, there was no consistent relationship of exposure intensities (sites) nor trends within years. An examination of all respiration rate data (1985-1987, WTF and laboratory), shows that there is no consistent depression of respiration rate in EM exposed macroplasmodia relative to controls.

Conclusions. The principal investigators conclude that the data from cultures grown at the UWP laboratory and *in-situ* at the WTF show that metabolic characteristics of the slime mold are varying with time. These changes are apparently not related to laboratory simulations or actual EM fields produced by an intermittent or fully operational ELF Communications System.

2.4 SOIL AMOEBAE

Soil amoebae are common soil organisms that are predators on bacteria. Bacteria, in turn, are important to the soil ecosystem because of their ability to mobilize nutrients needed for plant growth. To the extent that protozoa affect the number and types of bacteria in the soil, they also become a potentially important factor in soil fertility. Studies on protozoa and other related organisms have suggested possible EM effects on characteristics such as orientation, growth, and physiology.

In order to examine for possible effects from the operation of the ELF Communications System, the following aspects of soil amoebae are being studied:

- species and strain characteristics
- population size and activity
- growth and feeding.

In addition, select elements indicative of soil fertility are being monitored.

Studies on soil amoebae are being performed at three study sites in Michigan. One treatment site is located adjacent to an aerial portion of the MTF; the other is located adjacent to the grounded part of the MTF. A third site, the control, is located about nine miles from the nearest ELF System element. The aerial treatment site and the control site were the same as used in 1985; however, the ground treatment site had not been used prior to the 1986 field season.

Species and Strain Characterization. During 1988, eight types of amoebae (various generic and species levels) were isolated using soil enrichment techniques. To date, no differences between years or between sites have been reported in the types of amoebae present.

In 1988, as in previous years, the genetic diversity within a single species of soil amoeba, *Acanthamoeba polyphaga*, was determined by isoenzyme analysis. The number of genetic loci examined was increased from four in 1985 and 1986 to 14 in 1987 and 1988. The number of clones examined was increased from five at each site to 10 at each site in 1987. No significant differences were found between sites for the genetic diversity of *A. polyphaga*. The genetic heterogeneity has apparently decreased since 1985 probably in response to drought conditions experienced over the period 1986-1988.

Population Size and Activity. The size of the amoeba population is an ecological variable considered likely to influence the functioning of the soil system.

Soil samples for population studies are taken with a coring device. Coring locations within study sites are determined randomly, using a numbered grid system and a random number generator. The soil profile at study sites is typical of northern hardwood soils, i.e., with a sharp difference between the upper, organic horizon and lower, mineral horizon. In a typical core the 1- to 2-in. organic horizon is taken as one sample, while the top 2 in. of the underlying mineral horizon is taken as a second sample. A soil-dilution counting technique is used to determine the population size of each sample.

Studies to date have shown that the total amoeba population at any given moment consists of both vegetative (actively reproducing) and encysted forms. During the growing season there are cyclic changes in the total number of amoebae present, often increasing or decreasing by two orders of magnitude over short periods of time. Using analysis of variance techniques, no significant differences between sites were found in the numbers of cysts present in the organic or mineral soil horizons. Although there were significant differences between sites in the total numbers of amoebae present during surveys in June and July of 1987, there were no significant differences between sites in total numbers during the latter portion of 1987 or during the 1988 season. No statistical comparisons between years were reported for cysts or total numbers.

Growth and Feeding Activity. The purpose of this element is to determine the *in-situ* growth and feeding activity (i.e., predation on bacteria) of soil amoebae in buried culture chambers.

The study involves suspending a known species of amoeba (*A. polyphaga*) with a food bacterium in a physiological saline, all contained in a culture chamber. In order to simulate electric fields and currents present in the surrounding soil, the chambers are connected to buried collecting electrodes. Culture media with bacteria are replaced on a two- to three-week cycle using EM exposed amoeba from old cultures to inoculate the new media. During the first three days of a new culture periodic counts of amoebae were made to determine the changes in the number of organisms. A logarithmic transform of each site's early growth data provided a straight line plot (numbers over time) which was then quantified by regression analysis. Using a modified t-test, the resulting slopes of the lines were compared to examine for statistically significant differences between sites. In addition, the genetic heterogeneity of the cultured amoeba was determined at the onset (June) and termination (October) of the 1988 experimental period.

In 1984, preliminary studies of early amoeba growth in culture chambers at Michigan study sites indicated no significant differences between sites for amoeba growth rates without EM fields. Brief studies using EM fields were performed in 1986 at the WTF. There were no significant difference between exposed and unexposed chambers in the early growth rate of the amoebae. During

1987, growth studies were performed both in the laboratory and at the MTF. In the field, several problems in protocol and equipment were identified. In the laboratory, experiments examining amoebal growth and amoebal consumption of bacteria showed that the slopes of these two variables were the same at two different densities of amoebae. Bacterial suspensions incubated without amoebae did not change over the course of the experiment.

During 1988, cultures were grown with an excess of bacteria so as to support maximum amoeba growth. There were no significant differences between sites in the mean generation time (approximately 3.6 hr) of the cultured amoebae. In addition, there were no apparent differences before and after incubation in the MTF EM field environment for the genetic heterogeneity of the amoeba.

2.5 SOIL AND LITTER ARTHROPODS AND EARTHWORMS

Arthropods and earthworms play a major role in the decomposition of vegetation. These invertebrates shred plant material such as leaves and redistribute the remains in the soil habitat. The vegetative remains are then further degraded by soil microflora (see Section 2.2). For the purpose of detecting possible effects of the ELF Communications System on major agents of litter decomposition, this project is monitoring both the structural and functional aspects of the litter and soil invertebrate community.

The project employs one treatment site located adjacent to the antenna ROW at the MTF and one control site located at a distance west of the antenna. Both sites are situated in a maple-dominated deciduous forest. Although there are faunal differences between the sites, they have similar soils, vegetation, and microclimate.

In order to address faunal differences between sites, community indices and the characteristics of major populations common to both sites are emphasized in these studies. In addition to dominant groups, populations representing various roles in the soil habitat, such as predators and detritivores, are examined. To accommodate the various roles of the soil fauna, intersite comparisons of ecological equivalents and/or preoperational and operational comparisons of populations unique to the treatment site are

planned. Litter decomposition rates will provide an overall indication of the functional aspects of the soil community.

Surface Active Arthropods. This element examines the major arthropod fauna utilizing the surface layers of the soil at each site.

Diel and seasonal activity patterns of surface-active arthropods were assessed by consecutive, day and night, pit-trap samples taken once a week. In order to increase catches of surface-active arthropods, pit traps were provided with barriers that increased the effective area sampled by diverting moving arthropods toward the pit. Major groups trapped were springtails, mites, and ground beetles. The following paragraphs present information on data collected over the 1985-1987 period.

There were significant differences between sites and between years in the diversity of the springtail community. Based on the data collected to date, the sites differed in the relative dominance of major species, as well as in the occurrence of a few rare species. There were large differences between years and sites in the total number of springtails trapped. Nevertheless, within-year variations of density and frequency of developmental stages were synchronous at both sites. In addition to continued monitoring of density and diversity, linear regression techniques will be used to compare activity patterns between sites.

Three abundant species of mites were selected for possible future comparisons between sites and years. Two species have similar seasonal activity patterns at both study sites, however the density of each species was apparently greater at the control site. The third species also had higher densities at the control site, however seasonal activity patterns differed between sites. Data for the latter species will be reexamined for potential outliers.

Although the number of species of ground beetles continued to remain constant over the 1985-1987 period, dominance relationships also continued to change. Four species have remained numerous enough for a frequency analysis of numbers trapped over the season and for regression of nocturnal and diurnal captures to temperature. Preliminary examination of the pattern of numbers trapped throughout the season using linear regression statistical techniques showed no significant differences between sites within a given year.

Preliminary analyses indicate that temperature variables can account for up to 60 percent of the variation in the number of beetles trapped. In addition to monitoring diversity and trappable numbers (activity pattern), researchers are examining fecundity (number of eggs per female) as an indicator of the physiological state of adults. Preliminary analyses of two beetle species suggest that 4 to 10 percent differences should be detectable.

Soil and Litter Arthropods. The population and community dynamics of soil and litter arthropods are being determined from samples taken biweekly during the growing season. Litter and soil are sampled separately. The arthropods are then extracted by heat and sugar flotation techniques. Springtails and mites are the most abundant taxa in the litter and soil of both sites and are the major groups of interest. At the time of reporting, data were available for the period 1984-1987.

Although the diversity and annual mean density of the springtail community at study sites are comparable to those of similar deciduous forest communities, there continue to be significant differences between sites and between years within each site for these variables. The long-term trends in density of major groups and dominant species, however, were alike at both study sites. In addition, seasonal and annual patterns of developmental stages (sequence and peak percentage of the population for first instars, other juveniles, and adults) were significantly correlated between sites.

Identification and enumeration of mites continues to be a major problem in examining this heterogeneous group. Nevertheless, progress in examining three relatively abundant species has been made and other species are being considered for inclusion in this monitoring effort. Year to year changes in density are similar at both sites for each of the three species. Two of the three species also showed a highly correlated population composition (density of larvae, protonymphs, deutonymphs, and adults) between the study sites.

Diversity indices for both springtails and mites are different between sites and between years. In order to determine the standard error of annual diversity estimates, indices will be calculated for each sampling period within a season. Once determined, diversity will be examined using analysis

of variance techniques. Researchers also plan continued monitoring of diversity and density for a possible divergence in the existing relationships between sites.

Earthworms. The purpose of this element is to examine the major earthworm fauna inhabiting the soil and litter of the study sites.

Earthworms were extracted from litter using weak formalin, while those in soil were obtained by hand sorting followed by wet sieving. In 1987 earthworm samples were taken at biweekly intervals, May through July, and at monthly intervals through October; however in 1988 researchers returned to sampling at two-week intervals for the same period. The following summaries and analyses are based on data taken over the period 1984-1988.

Eight species of earthworms have been identified at the study sites. As expected, species diversity indices are low but are comparable to Canadian worm communities. There were no significant differences between sites for community diversity when total numbers of worms per species were averaged over the 1984-1986 period.

Population variables being examined are abundance (density), life cycle aspects (reproductive activity and recruitment), and distribution.

Average yearly densities and biomass of six worm species show significant differences between sites and between years. Although researchers did not consider these variables particularly sensitive, they will continue to monitor density and biomass as overall indicators of population trends.

Year-to-year densities of worms vary as functions of new cocoons produced, old cocoons hatched, and the effects of ambient conditions on reproductive adults. Although there were significant differences between years in cocoon densities and numbers of immature worms, recruitment and growth patterns were similar at both treatment and control sites. As expected, the number of reproductive adults and the production of cocoons are significantly related. Regressions of adults to cocoons show no significant differences between sites for *Dendrobaena octraedra* and *Aporrectodea turgida* (control) and *A. tuberculata* (treatment). These variables will continue to be examined for use in intersite comparisons and to determine the long-term consequences of reproduction and recruitment on overall population levels.

Cocoon weights are species specific and generally can be used as indicators of the physiological state of adults. Analysis of variance does not show any differences between sites or years for the cocoon weights of *D. octraedra*. Researchers estimate that differences of 3 to 10 percent in average cocoon weights can be confidently detected.

Previous analyses have shown that the vertical distribution of litter- and soil-dwelling earthworms was not significantly different between sites. During 1988 researchers investigated the potentially differing behavior of immature and adult worms. They found that the various stages were not equally distributed over the soil profile and concluded that the vertical distribution of the total population provides a better estimate of the worms' response to moisture that any stage alone.

Litter Decomposition. Litter decomposition provides an estimate of the overall functioning of all soil biota involved in organic matter breakdown and nutrient release. This system level response complements the faunal parameters under investigation and provides a context to evaluate effects seen at the community, populational and organismal levels of organization.

Litter inputs were determined by collection of leaves in litter traps located at each site. Traps were emptied weekly during the time of greatest leaf fall and monthly at other times. Samples were sorted by category, then oven-dried, cooled, and weighed.

In 1988, as in previous years, the total litterfall was significantly greater on the control site. Litterfall differences between sites was primarily due to inputs from non-dominant plant species (shrubs and popular trees). There was no significant difference between sites in the quantity or timing of litter inputs from dominant species (maple and basswood trees). Input values continue to be consistent with data reported for similar forests and latitudes.

Analyses of variance for the standing crop of litter shows no significant difference between sites in October, the time of the maximum. However, the standing crop of litter is significantly higher on the control site during most of the remaining season. Based on maximal standing crop and total litter

inputs, researchers estimate litter turnover rates of about one year at both sites.

Sampling forest floor litter is inherently imprecise; therefore, less variable estimates of decay rates were also obtained by examination of mass loss from leaves of known initial weight. Samples of dried maple litter were weighed and placed in mesh netting (20 mm) on the soil surface at both study sites. At intervals throughout the year, samples were retrieved, dried, and weighed. Correction for soil contamination was determined by combustion of ground samples and weighing the residue. At the time of reporting, 1988 samples had not been processed. Analysis of samples taken over the period May 1986 through September, 1987 showed no significant differences between sites in litter mass loss.

Values of 1986-87 decay rates determined from leaf packs yield turnover times of 1.3 to 1.4 years at the treatment and control sites, respectively. Forest floor turnover rates for 1986 were estimated at about one year. Actual rates probably lie between the forest floor and litter bag loss estimates.

2.6 NATIVE BEES

Enervated cells containing iron granules have been found in the abdominal segments of foraging honeybees. It has been speculated that these iron structures may be used in orientation and may provide a basis for the sensing of EM fields by bees. Behavioral changes such as increased dispersal, increased levels of activity, lowered overwintering survival, and modification of nest structure have been described as effects from fluctuations in the earth's magnetic field and from exposure to the EM environment associated with transmission lines.

Honeybees are rare in the forested areas in which the ELF Communications System is located. However, native bees are abundant and are of particular importance to ecological communities in the area as pollinators of the resident flowering plants. Native bees have coevolved with resident plants and are able to overwinter in the study area. Therefore, native bees, rather than honeybees, are being studied. Aspects of nesting activity, nest architecture, and the emergence of native bees have been monitored for possible EM effects from the operation of the ELF Communications System.

Observations on native bees have been made at two treatment sites and two control sites since 1983. Data on nesting activity were collected by direct observation as bees were constructing their nests. Information on nest architecture and emergence was collected using techniques that involve setting predrilled blocks of wood on shelved hutches ("trap nesting") at study sites. The wood blocks are split open and the biological aspects of the occupying bee species are then observed.

Each nest consists of a series of reproductive (cell) and nonreproductive (basal and vestibular) spaces within the bore of the hole. Each cell is lined with elongate leaves and is provisioned with pollen. After an egg is deposited, the open end of the cell is closed by a partition consisting of rounded leaves. The ends of the nonreproductive spaces are also closed with a series of plugs using rounded leaves and other material. Generally, the egg hatches and the larva molts through a series of stages to overwinter as a prepupa.

Over 40 species of native bees are known to occur in the ELF Communications System area, 20 of which will use trap nests. This study focuses on two abundant species, *Megachile inermis and M. relativa*.

Nesting Activity. Disorientation and agitation has been reported for honey bees foraging or building nests near transmission lines. This element examines for similar behaviors by observing the duration of foraging trips made by native bees.

From 1983 through 1986, an extensive effort was put forth in observing, recording, and determining the different activity patterns of various species of native bees. Statistical analyses performed during 1986 showed that efforts to record the time periods for construction and provisioning of cells with pollen required large amounts of observation time and yielded little and variable data. However, the duration of trips for nest material to cap cells (round leaves) was relatively short and less variable than other foraging behaviors. This latter behavior was selected for extensive observations during 1988.

In 1988, as in 1987, the duration of trips to retrieve round leaves was found to be shorter at the control sites than at the treatment sites. Nevertheless, there were no significant differences between sites in the

duration of the trips recorded for either year. Similar results were obtained for analyses of combined data taken over the 1983-1986 period. For all years, there were significant differences between observers, between dates, and trip order. Efforts to address the significant differences between observers will continue during 1989.

If future sample sizes are comparable to with those of 1987 and 1988, researchers are confident of detecting a minimum 2.1 fold increase in the duration of foraging trips (from 24 to 52 seconds). This magnitude of change is considered reasonable if bees are indeed disoriented.

Nest Architecture and Orientation. When honeybees were exposed to EM fields produced by a high voltage transmission line, their reproductive output was lowered, and they increased the amount of propolis at their nest entrance. If native bees respond to the EM fields produced by the ELF Communications System in a similar manner, they may alter such architectural aspects of their nests as reproductive spaces (cells), or produce thicker cell caps.

1985-1987 data for both species of bees has been analyzed. The analyses show that during the preoperational and transitional phases of the MTF there were no significant differences between sites in cell lengths and volumes. Similarly, there is no significant interaction between sites (intensity) and year for these two biological variables. Therefore, researchers should be able to detect effects on cell length and volume (if they occur) when the MTF becomes operational. Using the minimum number of nests collected, researchers are confident they can detect a difference of 14 percent in mean cell lengths for *M. relativa* and a 26 percent difference in mean cell length for *M. inermis*.

Data for number of cells per nest has been analyzed for *M. relativa* over the period 1985-1986. There were no significant differences between sites, years, nor were there interactions between sites and years. As the variability of cell numbers per nest for this species is relatively large, it may not be a sensitive indicator. Researchers are examining similar data collected for *M. inermis* to determine if it is less variable.

Analysis of 1985-1987 data collected for *M. inermis* show no significant differences between sites in the number of leaves used to construct a cell. If ELF EM fields have an effect on this variable, researchers are confident that

they can detect a 3 to 4 leaf difference in the current mean of 12 leaves per cell.

During 1988, researchers continued to collect information on nest plugs, and at the time of reporting, they were examining various methods for analyzing these data.

Since honeybees may use the earth's magnetic field to orient their comb, it is possible that fluctuating ELF magnetic fields could disturb any preference that native bees have in orienting their nests. Data on nest orientation continued to be collected during 1988, however statistical analyses were incomplete at the time of reporting. Previous analyses showed no preference for any cardinal compass point when bees oriented their nests.

Emergence and Mortality. High voltage transmission lines have been reported to lower the overwintering survival of honeybee colonies. In order to monitor for a possible similar effect in native bees, researchers are examining the proportion of nest cells that produce adults and the sources of mortality at test and treatment sites.

Completed nests were allowed to overwinter at study sites. During the spring, the nests were removed from the sites and taken to a laboratory, where they were split open and data on nest architecture were recorded. Cells were placed in individual plastic culture tubes and labeled with nest and cell identification numbers. Tubes and cells were kept outdoors at ambient temperature until emergence. Date of emergence, species, and sex of offspring were then recorded. Adults were released at the sites where their nest had been constructed the previous summer. Cells that showed no signs of emergence were opened and the contents were recorded to determine the condition of the bee.

Prior to their emergence in the spring, native bees are subject to mortality during any of several developmental stages (egg, larva, prepupa, pupa or adult). Failure to emerge is used as an indication of morbidity and the time of occurrence is associated with the easily identified developmental stage. Researchers equate pre-overwintering mortality with the egg and larval stages, and overwintering mortality with the prepupal stage. Dead pupae, adults that die in their cocoon, and emergent adults are considered as post-overwintering survivors.

Analysis of 1985-1987 data show that mortality is greater in the pre-overwintering stage than in the later stages. As there were large differences between years and sites in the mortality of pre-overwintering stages, and as the prepupal stage has the longest duration of exposure, the proportion of mortality in the prepupal stage has been selected for further hypothesis testing. One confounding factor is the inability to distinguish the prepupae of bees from those of a bee parasite. Preliminary analyses of combined bee and parasite data showed no differences between sites and years in prepupal mortality. Based on these analyses, researchers should be able to detect a three fold increase in prepupal mortality should ELF EM fields alter overwintering mortality.

2.7 SMALL MAMMALS AND NESTING BIRDS

Some laboratory studies performed at EM intensities and frequencies similar to those produced by the ELF Communications System have indicated effects to small vertebrates. Although these reports are controversial, many species of small mammals and birds reside in the ELF Communications System area, and in principle, any could be affected by the operation of the system.

As in the case of other studies in the Ecological Monitoring Program, this study examines several levels of biological organization for possible effects from the ELF system. Community characteristics are being used to assay for possible effects to many different species of resident mammals. In addition, two abundant species of mammals are being monitored for possible changes in population characteristics. Community and population characteristics of birds are being examined by other researchers (see Section 2.8).

Population and community studies are inherently variable; therefore, only pronounced effects are detectable when monitoring these levels of organization. Laboratory research indicates that if operation of the ELF Communications System has any effect on small vertebrates, the effect will be small. Therefore, to complement the population and community approach, specific attributes of individuals are also studied. The purpose of examining individual characteristics is to gather a sufficiently large set of data to detect small differences in exposure comparisons. The individual aspects

being examined are based on previous research and include reproductive, developmental, behavioral, and physiological characteristics of select species.

Those species selected for studies of population and most individual attributes are the deermouse, chipmunk, and tree swallow. The black-capped chickadee is also being examined but solely for physiological variables. The project uses five treatment sites in, or immediately adjacent to, the antenna ROW and four control sites with habitats similar to the treatment sites. Areas on the control sites have been cleared (sham ROWs) and are being treated the same as the antenna ROW.

Population and Community Studies. The purpose of this element is to monitor the small mammal community and select mammalian populations for possible effects from the operation of the ELF Communications System.

Live trapping was the primary method used to characterize the community and select populations of small mammals at study sites. In order to detect species that were not likely to be trapped, sign surveys and pitfall traps were also employed. Species diversity (an index of species evenness and richness) was determined and was used for intersite and interyear comparisons of the mammalian community. Densities of deermice and chipmunks (trappable population number) were used to monitor for possible effects at the population level.

Researchers anticipate that interyear comparisons will be of little value in assessing possible ELF Communications System effects on population variables, although intersite comparisons within a year will be useful. They estimate that a 20 percent change in diversity and a 5 percent difference in population densities at study sites will be detectable using current protocols.

In 1988, the treatment site had a significantly higher diversity of mammals than the control site. Except for a few species of larger mammals (bear, weasels and snowshoe hare) and shrews, the species composition of the treatment and control communities were similar. In 1987 the control site had

a significantly higher diversity than the treatment site; while in 1985 and 1986 there were no significant differences between sites.

As for the previous three years, the number of trappable chipmunks was significantly greater (t-test for intercepts) on the control site. Deermouse populations were not significantly different between sites in 1985 and 1986, however there have been significantly larger numbers of deermice on treatment sites in 1987 and 1988.

At present, researchers do not interpret the differences in diversity or population numbers as attributable to intermittent testing of the MTF. The lack of a consistent pattern from one year to another, as well as a lack of significant differences between sites for some years, appears to be due to site specific variables other than ELF EM fields.

Embryonic Development. Prenatal developmental stages are especially sensitive to environmental perturbations. At present, there are reports of effects on embryonic and fetal development from exposure to EM fields different than those produced by the ELF system. Possible EM effects on parental behavior could also have an indirect effect on development. The purpose of this element is to determine the incidence of abnormalities in embryonic development in tree swallows at treatment and control sites and to test for possible effects of the ELF Communications System on the incidence of these abnormalities.

Embryos of tree swallows are collected at several treatment and control study sites after four days of incubation. Embryos are dissected from the egg, preserved, and initially scored for normality. The preserved specimens will also be cleared, stained, mounted whole on glass slides, and examined in detail for more subtle alterations. This final, and more detailed, determination of normality will be carried out according to a "blind" procedure. The data presented here are based on the initial scoring of embryos.

Chi-square analysis of the frequency of developmental abnormalities for embryos collected during 1988 showed no significant differences between treatment (3 locales) and control (2 locales) sites. A chi-square analysis of data for control sites pooled across all years of the study (1985-1988) showed that the control locales were not homogenous and similar results were obtained for the treatment site locales. When the high control locale (1987) and high

treatment locale (1986, 1987) data were removed statistical analyses still showed no significant differences between sites. The frequency of abnormalities for the pooled treatment and control sites (without the high-incidence sites) was 10.0 percent.

Researchers do not consider the high frequency of abnormalities at the one treatment site to be associated with the operation of the MTF. They will continue to monitor all sites, including those demonstrating a high incidence of abnormalities. In order to examine for the cause of the elevated abnormalities at some sites, ambient and nest temperatures at each site will be recorded during the egg-laying period.

Parental and Nestling Behavior, Fecundity, Growth and Maturation: Tree Swallows. The purpose of this element is to monitor important aspects of the reproductive and postnatal growth processes in the tree swallow. Variables are parental attentiveness to eggs, numbers of eggs per clutch, hatching success within clutches, rates of postnatal growth, development of hatchlings, and nestling mortality.

Studies are carried out in clearings where researchers have erected arrays of nest boxes. The boxes can be opened to permit inspection and weighing of the young. Active nests are checked daily or every other day to determine the dates that eggs are laid, the number of eggs, hatching dates, and overall hatching success. Monitoring of the nests for nestling growth and mortality then continues until all young fledge. Parental attentiveness to eggs is monitored using temperature probes. Attempts to monitor parental attentiveness to nestlings using video recording devices has proved to be too variable and has been discontinued as a study element.

Clutch size (maximum number of eggs laid in a nest) has been used as an indicator of fecundity. In 1985 and 1986, treatment sites had significantly higher clutch sizes than control sites. However, in 1987 and 1988 there was no significant difference between sites. Mean clutch size in 1988 was 5.4 and 5.3 eggs per nest at treatment and control sites respectively. Researchers continue to collect and analyze data on available food supply (insect biomass) as one possible factor influencing clutch size.

Average egg temperature during incubation was used as an indicator of parental attentiveness to eggs. Using 1988 data, nested analysis of variance

showed no significant differences between sites in egg temperature during the course of incubation. Using mean incubation temperatures from both 1987 and 1988 in a two-way analysis of variance also failed to show a significant differences between sites. These analyses did, however, indicate that much of the observed variation was due to differences between nests.

Hatching success during 1988 was 92 percent at the treatment and 91% at the control sites, however these differences were not statistically significant. When 1985-1988 data was pooled the likelihood to hatch was found to be independent of both site and year. The actual number of birds to hatch in 1988 was greater on the treatment site (5.0 young/nest) than on the control site (4.8 young/nest). When hatch rate data for the last four years are combined there were significant differences between years but not between sites.

There was no significant difference between sites in the postnatal landmarks of mean number of days to eye opening or feather eruption during 1988. In 1988, the mean number of days to eye opening was 7.3 days at treatment sites and 6.7 days at control sites; the mean number of days to feather eruption was 8.2 days at treatment sites and 8.8 days at control sites. For both variables in all years there were significant differences between nests at a given site.

In order to examine growth rates, periodically measured values were fit to models. Body weight, tarsus length, and ulna length data (1985-1988) best fit logistic models, while wing growth data best fits an exponential model. The models were used to produce parameters (e.g., rate of growth at the inflection point and the inflection point) used in a nested analysis of variance. For rates of weight, tarsus length, ulna lengths and wing growth, no significant differences between sites were detected for 1988 or previous years.

In 1988, fledgling success was significantly greater at treatment sites (85 percent) than at control sites (69 percent). The actual numbers of young to fledge per nest during 1988 was 4.3 and 3.3 at treatment and control sites respectively. Data for fledgling success and numbers of young to fledge pooled over the period 1985-1988 data, show significant differences between years but not between sites. It is postulated that differences between years may be due

to an episode of inclement weather during 1986 and to the presence of inexperienced breeders at control sites during 1985.

Values obtained in these studies of fledgling success, hatching success, and clutch size are similar to those reported in the literature for other studies of tree swallows.

Data for eggs, nestlings, and nests were used to assess mortality using the Mayfield Method. It is uncertain whether this method is appropriate for low mortalities. Units used to examine data for 1985-1988 were egg days, nestling days, and nest days. Egg and nestling mortality during 1988 was significantly higher on control sites when data from all study plots were combined.

Parental and Nestling Behavior, Fecundity, Growth and Maturation: Deermice. The purpose of this element is to monitor important aspects of the reproductive and growth processes in deermice. Variables are maternal attentiveness to nestlings, number of young born per litter, proportion of young surviving until weaning, rate of postnatal growth, and rate of development of nestlings. (Note: the prenatal development of mammals is not being studied because reproductive females would have to be killed in order to examine the fetuses. The removal of the number of females required to meet statistical sufficiency for these studies would have adverse effects on the local population.)

Large, open enclosures are being used to restrict the movements of deermice during studies of behavior, fecundity, and growth. The deermice to be studied are captured in mixed deciduous forest near the enclosure sites. The animals are paired, and when the female is pregnant, she is transferred to the large enclosure to give birth and rear the young to weaning. The attentive behavior of the mother is monitored by using treadles attached to nest boxes and feeding stations.

Growth studies to date have shown that growth curves of temporal change in the body mass of nestlings are different between litters. Therefore, growth rates have been estimated using linear regression analyses for growth of each individual and combined growth of all individuals in each litter. Examination of combined growth during 1988 using analysis of variance showed

significant differences between litters but no significant differences between sites. In 1988, as in previous years, the age at eye opening and the age at incisor eruption were not significantly different between sites.

Only three females of 44 at the control site and two females of 30 at the treatment site showed normal parental behavior during the 1988 monitoring period. There was no significant difference between sites for the time spent out of the nest by normal females. The other females either abandoned the young, ate them, escaped, or in several cases, the treadle system malfunctioned. As 300 hundred females per site need to be monitored for statistical sufficiency, this element will be discontinued.

Homing Studies. Animals are able to find food and escape predators more effectively in their home range or territory than in less familiar areas. Published information suggests that magnetic fields are one of several cues used in the orientation of some birds and mammals. Thus, any disturbance of the ability to return to, or use, a home range could decrease the probability of survival. The purpose of this element is to monitor the homing ability of tree swallows and deermice to assess for possible effects from the operation of the ELF Communications System. The variables being examined are the likelihood to return (number of displaced individuals that return home in less than 300 min.) and the amount of time taken to return home.

Adult birds from treatment and control sites were captured at nest boxes while brooding their young. Captured birds were banded, color-marked, and taken to release sites. (Release sites are located in open areas 30 km from the capture site.) The direction of the release points from the nest sites requires birds returning to their nests at treatment sites to cross both east-west antenna elements of the MTF. Birds taken from a single control site are displaced at an angle and distance similar to that used for birds taken from the treatment sites, but do not cross or come near any of the antenna elements. Observers located near the nest boxes record the times at which the displaced birds return.

Data from three years of study are conflicting, with 1986 and 1988 data showing no difference between sites in the likelihood to return and 1987 data showing a significant difference between sites. Examination of pooled data over the 1986-1988 period by analysis of variance showed that birds captured

on treatment sites have a significantly greater likelihood of return as well as a more rapid return than birds captured on control sites. In 1988, the mean time to return to treatment sites was 137 minutes compared to 190 minutes to return to control sites.

Chipmunks and deermice were captured on a trapping grid at treatment and control sites. Displacements took place during, or just prior to, the next activity period following capture; deermice were displaced at dusk and chipmunks in the morning. Individuals were displaced either to the south or west of the trapping grid, with each animal displaced 450 m from the trap at which it was captured. The displacements to the south were through relatively continuous forest, while displacements to the west required the returning animals to cross the antenna ROW or sham ROW. Once an animal was displaced, traps on the grid were checked morning and evening for the following five days.

There were no significant differences between sites in the frequency of return of displaced chipmunks or deermice in 1988. Previous studies have shown no significant differences between sites, genders, or directions of displacement.

Physiology: Peak Aerobic Metabolism. The purpose of this element is to determine the peak aerobic metabolism of chickadees and deermice during an annual period of severe stress (winter). This variable provides a general index of an animal's health.

Black-capped chickadees and deermice were collected during the winter along the ELF Communications System's ROW and at a control site. Animals to be tested were held at an outdoor facility with food and water provided ad libitum. Tests for peak metabolism were performed in an ethanol-cooled chamber using a version of the helium-oxygen method. Test equipment was located at a laboratory in Crystal Falls, Michigan, while the holding facility was situated several miles south of the city. Once tested, animals were released at their collection site.

During 1988, data from all previous years were reviewed for accuracy and completeness. The following presents analyses of data from the winter of 1988 as well as reanalysis of data from prior years.

A two-way analysis of covariance was performed on data pooled over the period 1986-1988 with one factor being site and the other being year. There were no significant differences between sites or between years in the peak rate of oxygen consumption of deermice; nor was there a significant interaction between sites and years. Researchers conclude that peak metabolic rates for deermice in the years prior to full activation of the MTF have been stable from year to year and similar at both treatment and control sites.

A similar analysis of covariance was performed on pooled data for chickadees. Peak metabolic rates for birds captured on control plots was significantly larger (4 percent) than birds captured on treatment plots. There were no significant differences between years or year-plot interactions. Researchers conclude that peak metabolic rates for chickadees in the years prior to activation of the MTF have been stable from year to year but somewhat different between sites. The cause of the intersite differences is unknown and site differences will have to be taken into account in evaluating an operational MTF.

2.8 BIRD SPECIES AND COMMUNITIES

Many species of birds migrate from a nesting range to an overwintering area and back again. Successful migratory movement requires a mechanism that permits judgment of direction in order to arrive at the appropriate location. Experiments have indicated that birds are sensitive to magnetic cues and use such cues, along with others, for orientation during migration. The magnetic environment in which a bird is raised may also be important in its development of orientation ability.

This project monitors for possible effects to resident birds, migratory birds that breed in, and birds that migrate through, the ELF Communications System area. The study concentrates on characteristics such as total species richness and total numbers of birds, number of individuals for abundant and common bird species, and numbers of birds within selected guilds. In order to properly qualify results, researchers have also examined habitat structure on treatment and control transects, possible "edge effects" caused by the antenna ROW, and the variability due to differences between observers.

A line transect method (variable width) was used to census bird community characteristics. Observers walked a designated transect and recorded information directly from sightings or indirectly from bird songs. The variables recorded were species, sex, behavior, perpendicular distance from transect, and distance along transect. In 1988 as in 1986 and 1987, the characteristics of both the breeding and migrant bird communities were examined for each of five periods: spring migration (May), early breeding (June), late breeding (July), early fall migration (August) and late fall migration (September).

Study sites consist of 10 transects (five treatment and five control) in Wisconsin and 10 transects in Michigan. Treatment transects are parallel to and about 125 m from the edge of the antenna ROW. Control transects are variously oriented and generally at distances greater than 10 km from the antenna. Control transects do not have sham corridors located adjacent to them. Each transect is subdivided into eight 500-m segments.

To date no consistent pattern has emerged to demonstrate that birds are more or less abundant on treatment relative to control segments in either state. Few significant differences have been found at the community or species level and significant differences in one season or year have generally not been repeated in subsequent years or seasons.

Effects of Habitat Structure. Habitat structure has a pronounced influence on many aspects of bird communities. The construction schedule for the ELF Communications System allowed investigators to use preoperational and operational comparisons to examine for possible changes due to EM fields in Michigan. However, because the antenna was operating prior to the start of this project, detection of possible effects to the bird community in Wisconsin could not be determined without first accounting for differences in habitat structure on treatment and control transects. A two-year habitat assessment was completed during 1987.

Statistical analyses of vegetation on Wisconsin study sites showed that treatment transects had more coniferous and lowland habitats than did control transects. Fifteen treatment and control transect segments located in Wisconsin were paired based on habitat similarity. Nine of 44 comparisons of abundant species showed significant differences between the paired segments in

the number of individuals present; in seven of the nine cases, numbers were higher on treatment segments. Previously reported results from pooled treatment and pooled control data (1985-1987) will be reexamined during 1989 using the paired segment approach.

Qualitative assessment of vegetation on Michigan study sites also showed that treatment transects had more coniferous and lowland habitats than did the control transects. Comparisons of avian community characteristics on treatment and control transects segments in Michigan will continue to be pooled and examined by analysis of variance techniques.

Species Richness and Abundance of Individuals. During 1988, bird abundance and species diversity were highest during June in Michigan and during May in Wisconsin. Except for the total number of individuals per Michigan segment during May, there were no other statistically significant differences in community parameters in either state.

Particularly abundant species (all seasons) present on study transects during 1988, included the Nashville Warbler, Ovenbird, White-throated Sparrow, Red-eyed Vireo, Black-capped Chickadee, and Golden-crowned Kinglet. Among these and other abundant species, seven of 34 comparisons revealed a significant difference between treatment and control segments in Michigan; five of the seven had a greater abundance on treatment segments. In Wisconsin, two of 28 comparisons indicated a significantly higher abundance on treatment segments. No other comparisons of Wisconsin segments indicated significant differences. Examination of common bird species present in Wisconsin showed 24 of 114 comparisons were significant; in 8 of the 24, the numbers of individuals were higher on the treatment segments. In Michigan, 14 of 90 comparisons were significant, 8 of which showed higher numbers of individuals on treatment segments. Few species have consistently shown significantly greater numbers on either treatment or controls segments among seasons within a year or within seasons between years.

When results from all years (1986-1988) were combined, analysis of variance showed no treatment effect in Wisconsin during any season and a significant treatment effect for May in Michigan. These significant differences in Michigan, where the transmitter was operated only periodically at low power, are most likely due to habitat differences.

Guild Analysis. Species that belong to the same guild share important biological characteristics. In monitoring for possible effects from the ELF Communications System, treatment and control comparisons of the abundance of guild members may be more meaningful than similar comparisons of the entire bird community present on treatment and controls.

Those species of birds found on study sites were classified into guilds on the basis of foraging location and preferred breeding habitat. The number of individuals for each guild type on treatment and control transect segments were compared for the 1988 season. Few significant differences (5 of 50 comparisons) between treatment and control segments existed in the abundance of individuals from foraging guilds, however there were more significant differences (14 of 60 comparisons) in the number of individuals from habitat guilds. The latter findings provide additional support for the notion that habitat differences are primarily responsible for the observed differences in bird distributions.

Edge Effect. The presence of a cleared ROW is a potential source of error when comparing treatment and control (no ROW) bird community characteristics. The variety and density of birds are known to be larger at the edges of plant communities. Vegetation changes associated with clearing of the antenna ROW are different from undisturbed habitats on control transects or in undisturbed areas adjacent to the antenna. Because clearing of sham corridors on control sites was not feasible, treatment transects were placed at a distance from the antenna ROW in an attempt to eliminate edge effect variability from the study design.

Previous analyses conducted on 1986 and 1987 data considered the possibility that differences between treatment and control segments were due to edge effects. Except for one species, the indigo bunting, there were no significant differences between sides of the transects in the abundance of a given bird species. Thus, there appears to be little, if any, direct effect of the ROW and associated edge habitat on the study's results.

Observer Differences. Another potential source of error in censusing is the variability between observers in detecting and recording bird species and numbers. Several factors may contribute to the variations, including avian

density, the observer's hearing acuity, and his or her ability to estimate distance to singing birds.

This potential source of error, checked annually since 1984, was again examined in 1987. In 1987, two observers (separated by 10 minutes) censused the same eight transect segments during the June breeding season, when almost all bird data are determined by sound. The same two observers censused the transect in 1987 as had done so in 1986; however, the order of their passage along the transect was reversed. In 1987, as in 1986, the first observer to pass along the transect recorded more birds than the second observer. Because the order of the observers' passage was the reverse of that used in 1986, researchers feel that the differences between observers were attributable to behavioral changes in singing and flushing of some birds caused by the passage of the first observer.

2.9 WETLAND FLORA

In addition to the upland flora described in Section 2.1, wetland ecosystems are also relatively abundant in the ELF Communications System area. Wetlands play a valuable role in supporting diverse food chains, providing wildlife resources and, under some conditions, maintaining natural hydrologic systems. They are sensitive ecosystems that are easily modified by environmental perturbations.

Laboratory studies at ELF frequencies and intensities higher than those produced by the ELF Communications System have affected plants. It has been hypothesized that EM fields may affect biota by altering the transport of materials across their cell membranes. Therefore, variables important to the stability and functioning of wetland systems and which could be affected at the membrane level were monitored. The types of variables examined were foliar nutrient content, stomatal resistance, litter decomposition, and nitrogen fixation.

A common type of wetland found in the ELF Communications System area is the peatland. Three types of peatland plants (herbs, shrubs, and trees) were examined in 11 peatland sites near the WTF. The study sites were of four EM exposure types: antenna, ground, intermediate, and background. The antenna and ground sites (treatment sites) were located adjacent to the transmitting

elements they describe. The background sites (control sites) were located more than six miles from the nearest transmitting elements and had EM intensities two orders of magnitude less than the treatment sites. Intermediate sites were located so as to have EM intensities between those of the treatment and control sites.

Each site was rectangular and oriented with the long side parallel to the nearest transmitter element. Each site was subdivided into six subplots, with a shallow well located at the center of each subplot. Ambient environmental factors (e.g., ground water chemistry and temperature) were taken at the well; biological samples and other measurements were taken from areas immediately adjacent to the well.

The 1987 field season was the last for collection of data at the WTF. During 1988, researchers completed analysis of 1987 samples and prepared a final report that summarized the results from five years of study. Based on the results of these studies, researchers conclude that ELF EM fields generated by the WTF had no measurable effect on bog plant species or their ecology. The following summarizes the findings of this study.

Foliar cations. Foliar cations are important in plant physiology as active constituents of a number of biochemical reactions. Peatlands of the type found in the ELF Communications System area are relatively cation-poor environments, and the plants that exist there tend to conserve minerals by a variety of methods. As ELF EM fields may directly affect the transport of cations across cell membranes, four species of wetland plants were monitored for their foliar cation content.

Foliar tissue samples were collected during each growing season. Concentrations of cations were highly variable between sites, months, and years. Each sample period was statistically evaluated independently of the others to reduce the sources of variablilty. Five significant treatment effects were detected in 79 separate statistical analyses, a frequency expected by chance alone. In addition, the significant differences include three different species and three different months, thus failing to show a consistent pattern. Further analyses using both multiple regression and canonical correlation showed that only a small percentage of the variance in foliar nutrient content was explained by the intensity of EM fields.

Researchers concluded that ELF EM fields have not influenced the foliar cation content of bog plants.

Stomatal Resistance. The possibility of EM field effects to the transport of ions across biological membranes has been noted. The transport of ions, in turn, may indirectly affect water uptake through osmotic processes or may directly restrict stomatal opening. In some plants even a mild potassium deficiency can hamper stomatal opening. Therefore, the stomatal resistance was examined to determine the physiological status of wetland plants exposed to EM fields from the ELF Communications System.

The stomatal resistance of Labrador tea leaves on treatment and control sites was measured twice in 1986 and twice in 1987. Nested analysis of variance found one significant difference in treatment effect (July 1987) for the four measurement periods. Further statistical examination of the July 1987 data using multiple regression showed that the regression could only account for a small amount of the variability in stomatal resistance (29 percent) and no (ELF EM) treatment variable was selected by the model for inclusion in the analysis. Treatment variables were selected for inclusion by the multiple regression model in two of the remaining three measurement periods. In one case the treatment variable had a negative relationship to stomatal resistance, while in the other the slope was positive. Thus, the statistical analyses provided conflicting indications of the possible effects of ELF EM exposure on stomatal resistance. The researchers conclude that there is no biologically significant stomatal response to the ELF EM fields produced by the WTF and that other factors must be considered in explaining their results.

Decomposition. The decomposition of plant material, a major process in bog development and change, is accomplished by microorganisms. As a group, microorganisms have been shown to be affected by ELF EM fields at intensities greater than those produced by the ELF Communications System.

Cellulose wood pulp and leaves of Labrador tea plants were used in the decomposition studies. After various periods of time these materials were retrieved, dried, and reweighed to obtain percentage weight loss. No significant treatment effects on the cellulose decomposition wood pulp were

detected using nested analysis of variance techniques. It should be noted that the variability of cellulose decomposition was high.

Analyses of variance showed significantly greater decomposition for Labrador tea samples emplaced at antenna sites for a year (October 1986-October 1987) than those emplaced at background sites for the same period. Other possible relationships (e.g. ground to control, antenna to intermediate) were not significant and there were no significant treatment effects in the decomposition of Labrador tea over the period June 1985-June 1986 or June 1985-October 1985. Stepwise regression analyses did not select EM treatment variables for inclusion in the model. Other analyses showed that the depth to water table and amount of moss covering litter bags to be important components in explaining decomposition rates at the study sites. In 1987, researchers found more litter bags covered with moss at the antenna site (62 percent) than at the other three types of sites (23 to 35 percent). Based on these findings it was concluded that ELF EM fields had no detectable influence on the decomposition of organic matter in bogs.

Nitrogen Fixation. Biological nitrogen fixation is important in low nitrogen environments such as peat bogs which receive most of their nutrients from the atmosphere. Several studies have indicated a difference between actual amounts of nitrogen available in bogs and the amount supplied to them in rainfall. Nitrogen fixation and recycling is carried out by symbiotic bacteria associated with lichen, mosses, and higher plants. This symbiotic association is considered possibly sensitive to ELF EM exposure though membrane permeability and/or biochemical pathways.

Studies were initiated in Wisconsin bogs during 1984 by using alder cuttings and bacterial nodules. This approach was discontinued because a sufficient supply of uniform plants could not be propagated from seeds or cuttings. Subsequently, nitrogen fixation by heterotrophic microorganisms associated with the peat substrate was examined. The latter efforts were hampered by high variability in nitrogen products and sampling protocols. All effort on this element were terminated during 1986.

2.10 AQUATIC BIOTA

Aquatic biota, particularly fish, have been shown to use, or react to, weak ELF EM fields. The purpose of this study is to monitor a riverine ecosystem for possible effects on aquatic biota from long term exposure to the low level EM fields produced by the ELF Communications System in Michigan. Populational aspects as well as the functional and structural components of three major aquatic communities (i.e., periphyton, aquatic insects and fish) are examined.

Two similar sections of the Ford River are used as matched study sites. One site is located adjacent to the north/south leg of the MTF (treatment); the other is located more than 10 km downstream (control). No major tributary occurs between the sites. At each site ambient environmental factors are monitored and ecological experiments occupy adjacent stream segments. In order to determine the migration pattern of fish, four additional sites are located upstream of the control site.

2.10.1 Periphyton

Periphyton are a community of microscopic plants and animals associated with the surfaces of submerged objects. Unlike organisms suspended in the water column, the structural and functional aspects of the periphyton community at a given location are governed by conditions at that point. Because they show responses immediately at the source of a perturbation, periphyton are being used to assess for possible changes in the aquatic community due to the operation of the ELF Communications System.

As the periphyton community is dominated by diatoms, they are emphasized in monitoring of structural aspects, however functional aspects such as chlorophyll, biomass, photosynthesis, and respiration are determined for the entire community (i.e., diatoms, plants other than diatoms, and animals). Quantitative determinations are made by collection of periphyton colonizing artificial substrates of known surface area. Preliminary studies in the Ford River have shown that the periphyton established on glass slides were representative of the periphyton community found on natural substrates.

Statistical comparisons between sites used the paired t-test, however, "before and after, control and impact site" (BACI) techniques were emphasized

in most analyses. The BACI technique compared the mean of the "before" differences between control and impact (treatment) sites to the mean of the "after" differences between sites by using an unpaired t-test. For preliminary statistical analyses, samples collected from June 1983 through April 1986 are considered "before" data and samples collected from May 1986 through September 1988 are considered "after" data. Low current testing was initiated at the MTF in July of 1986. In order to construct a complete picture of relationships, researchers have also calculated a correlation matrix for all ambient and biological/ecological variables.

Structural Aspects. The purpose of this element is to monitor select variables of the diatom component of the periphyton community. Indices for species diversity, evenness, and abundance allow the detection of subtle shifts in the community's makeup, while total cell density and biovolume of diatoms gives an indication of any overall change in the dominant biota of the community.

Glass slides emplaced at study sites for 28 days were used to identify and enumerate colonizing diatoms. The community that develops on emplaced slides most often consists of 50 to 70 species of diatoms. Because diatoms vary greatly in their size distribution, the number of individuals (total cell density) alone does not give an adequate picture of the community's makeup. Therefore, cell volume measurements for the dominant diatoms were also determined. Volume estimates were multiplied by the density of each species and summed to provide an estimate of the total biovolume for all cells present.

Since 1983, the seasonal pattern has continued to be high diversity and evenness during winter, with lower values in summer. Paired t-tests of species diversity and evenness failed to show a significant difference between sites during 1987-1988, or for data pooled over the 1983-1988 period. BACI comparisons, however, did show a significant difference between before and after data. Further BACI analyses showed very few significant differences between comparisons of individual "before and after" years (e.g., 1984/1988), indicating that factors other than ELF EM fields are probably the cause of the difference.

The seasonal pattern for the density of diatoms continues to be lower densities during the winter than during the summer. The time and duration of peak diatom density was found to be highly variable between years occurring any time within a four month spring-summer period. Paired t-tests of density showed no significant differences for data pooled over the 1983-1988 period, however, BACI comparisons did show significant differences between "before and after" data. The high density of diatoms occurring after April 1986 may be due to factors associated with the extremely dry conditions experienced during May and early summer of the period 1986-1988.

Comparisons of individual cell volumes or total biovolume (cell volume times density) of 20 dominant diatom species failed to show significant differences between sites for 1987-1988 or for data pooled across years. There were no significant differences in "before and after" comparisons of these variables when examined using BACI analytical techniques.

Functional Aspects. As indicated previously, numbers or types of diatoms alone do not provide a complete characterization of the periphyton community. The purpose of this element is to monitor such aspects as chlorophyll a, organic matter accumulation, photosynthesis, and respiration, which represent the functioning of the entire community.

Slides were emplaced in the Ford River for 14 days for determinations of accrual rates and 28 days for determinations of standing crop estimates of chlorophyll a, phaeophytin a, and organic matter biomass. Fluorometric methods were used for analyses of chlorophyll and phaeophytin. Organic matter biomass was determined using changes in ash-free dry weight per unit area.

Annual patterns for chlorophyll a standing crop and accrual were similar. The annual pattern was one of winter lows, with a peak value occurring in July or August. There was considerable year-to-year variability in both standing crop and accrual rates, due to the presence (or absence) of secondary peaks (March through June) and/or the magnitude of the summer peak. Secondary peaks occur when spring conditions are dry, i.e., low stream flows and relatively warm temperatures. Most biological correlates with algal standing crop (e.g., density and organic matter) as well as species diversity have increased since 1986 probably as a consequence of very dry weather experienced during late spring and early summer of the 1986-1988 period.

There were no significant differences between sites in chlorophyll a standing crop, accrual rates during 1987-1988, nor accrual rates for pooled data from the 1983-1988 periods (paired t-tests). BACI analyses did show significant differences between "before and after" comparisons of standing crop and accrual rates.

Organic matter standing crop and organic matter accrual rates showed the same annual pattern as chlorophyll. Paired t-tests showed the same results as chlorophyll a, however, BACI analyses of data on organic matter standing crop showed no significant difference between before and after periods. Organic matter accrual rates will be included in next year's annual report. Like chlorophyll a, organic matter standing crop was significantly correlated with temperature and discharge.

As there were no significant differences between sites based on the paired t-tests, it seems unlikely that the differences between before and after comparisons are a result of ELF EM exposures. Significant positive correlations between chlorophyll a as well as organic matter and water temperature, coupled with increasing water temperatures during the drought periods in the spring and summer of the 1986-1988 period, indicate that before and after differences are related to climate factors.

Changes in dissolved oxygen concentrations in light/dark chambers with periphyton-covered substrates were used to estimate community productivity and respiration. There were no significant differences between sites in net production, respiration, nor gross production of the community over the period 1984-1986. Preliminary examinations of statistically unanalyzed 1987 and 1988 data indicate results similar to that obtained for the 1984-1986 period. It now appears that this approach offers a robust means for monitoring and all data will be analyzed using BACI techniques for the next annual report.

A correlation matrix was generated using all the available data collected from each individual site over the 1983-1988 period. Although some water chemistry constituents appeared to influence the biological parameters at one site more than another, there was general agreement between sites in the relative influence of environmental factors and water chemistry. The results of the correlation analyses agreed with previously reported analyses using multiple regression techniques.

2.10.2 Aquatic Insects

As part of the integrated studies of the aquatic ecosystem, insects are being monitored as representative of the primary and secondary consumer levels in the aquatic food chain. These studies examine the important functional insect groups, such as shredders, collectors, predators, and grazers. Both community and individual aspects of organization are being monitored. The community aspects are leaf litter processing; insect colonization patterns on leaf litter and artificial substrates; and the frequently used structural descriptors of community change such as species richness, individual abundance, and species diversity. The monitoring of individual aspects emphasizes changes in individual behavior such as alterations in movement patterns and feeding activity.

Feeding Activity of Grazers. The purpose of this element is to monitor the relationship between the producer and primary consumer trophic levels. This was accomplished by examining the periphyton community for effects from insect grazing.

The study approach uses streamside chambers to which are added tiles precolonized with periphyton and grazing insects. The chambers are subdivided so as to allow the introduction of different numbers of grazers (0 to 30) per experimental run. After a period of time the tiles are removed and the periphyton are analyzed for chlorophyll a, organic matter biomass, and diatom cell counts. Development of data collection techniques was initiated in 1985 and continued into 1988. Final identification and enumeration of diatom species collected during 1988 will be completed during 1989.

Preliminary studies performed during 1985 indicated that grazing by a caddisfly caused marked species and diversity shifts in the diatom community. Nevertheless, except for shifts in dominance of a few minor taxa, there were no significant differences between grazed and ungrazed tiles for any aspect of the periphyton community during 1987. Researchers attribute the lack of significant grazer effects during 1987 to siltation problems encountered during the course of the study. Siltation also occurred during 1988 studies, however, analyses have not yet been completed on these samples. In 1989, researchers plan to use only those data collected during periods without

storms. In both 1987 and 1988 there were significant differences between sites in organic matter accumulation but not in chlorophyll a accumulation.

Benthic Insect Community. The purpose of this element is to monitor the major organisms constituting the primary and secondary consumer trophic levels, i.e., benthic insects, for changes in community structure and function.

Riverine substrates contained in sample baskets were emplaced at study sites for one-month periods at intervals throughout the spring and summer seasons. Insects were collected from the substrates, identified, and counted. Numbers of individuals, diversity, richness, evenness, and percent numerical dominance for selected species were determined for each replicate. Total sample biomass and the biomass for functional feeding groups were also determined. For those insects with high numerical abundance, mean dry weight per individual was also computed.

The structural community parameters (taxon diversity, evenness, and richness) have an annual pattern of high values during the summer and low values during the spring. Water temperatures were positively correlated with diversity and taxon richness. Generally, taxon diversity, richness, evenness, and number of individuals were higher at the treatment site than at the control site. Chironomids have been present in consistently high numbers in the Ford River, and their abundance has had a marked effect on the structural community parameters. Sufficient samples are being taken to have a 95 percent confidence that the determined mean was within 40 percent of its estimated value at the 0.05 level of significance. After full power operation of the MTF, BACI analyses will be performed on the data.

Over the five-year period 1983-1987, distinct seasonal patterns were found for total biomass of insects. The annual pattern of insect biomass at both study sites showed summer (July-August) and spring (February-April) peaks, with troughs over the October-December period. After the summer of 1986 there was less similarity of pattern between the sites. Insect biomass was significantly correlated with water temperature and diatom density. Graphic presentations indicate higher insect biomass at the treatment site than at the control site.

Total biomass values were partitioned into functional feeding groups including: predators, collector-gatherers, collector-filter feeders, and shredders. All but the latter had seasonal patterns similar to that described for total insect biomass. Predators contributed more to the total biomass than the other feeding groups. Shredders had less influence on total biomass, and were not significantly correlated to diatom densities.

Future plans include examining total biomass values during transition periods to compare preoperational and operational periods using regression techniques. Researchers will also examine abundance for differences between sites using a BACI statistical design.

Leaf Litter Processing. In headwater streams such as exist in the ELF Communications System area, only a portion of the energy supply to the ecosystem is provided by aquatic plants and algae. The maintenance of community structure is largely dependent on the input of organic materials (i.e., leaves) from riparian vegetation. Macroinvertebrate consumers, mainly insects, process the leaves, making consumer biomass available to higher trophic levels (predators).

Processing and insect colonization patterns using "leaf pack" bioassay techniques were used to monitor for possible EM effects to this energy pathway. Leaf processing rates (mass loss) were used to quantify the overall feeding activities of the colonizing organisms, while species diversity, evenness, and richness were used to characterize colonization patterns. Processing rates were determined for fresh and dried green leaves emplaced during early August 1988 and retrieved at regular intervals over a two month period. At the time of reporting, data on 1988 leaf processing rates were available, but data on those insects colonizing leaf packs were not ready for examination. These latter data will be presented in the next annual report.

Comparison of data collected over the period 1982-1988 to literature values show that processing rates of fresh leaves are fast at both sites. Similar comparisons using autumn abscised leaves show intermediate processing rates at the treatment site and slow rates at the control site. The rate differences appear to be ascribable to differences in physical and biotic characteristics of the sites. Relative differences between the sites in the

rate of leaf processing have been consistent year to year and therefore are amenable to monitoring of the leaf processing community.

There were no significant differences between sites in the rates of processing fresh or autumn-abscised leaves during 1988 (t-test). Analyses of variance showed that fresh leaves were processed significantly faster at the treatment than at the control for only one emplacement interval (41 days) out of the six examined during 1988. No significant differences between sites were noted for samples emplaced during the summer of 1987.

During 1987, as in 1986, structural community parameters (taxon diversity, evenness, and richness) were significantly larger at treatment than at control sites. The percent dominance of chironomids generally increased over the period of emplacement of leaf packs. The steady decrease in taxon diversity and evenness during the latter part of emplacement was attributed to the steady increase in numerical dominance by chironomids. In summary, after being emplaced for more than four weeks, leaves at the treatment site usually supported a more diverse and equitable insect community than leaves emplaced at the control site. Once the MTF becomes operational, "before and after" statistical comparisons will be made for the structural parameters of the 24-28 day community.

Functional community parameters for colonizing organisms include total insect biomass (adjusted to leaf biomass), biomass of functional groups, and the mean (dry) weight per individual for representative species within each functional group.

Total insect biomass displayed a pattern of constant increase over the period of leaf pack emplacement (76 days) at both study sites. As for the structural community parameters, the least variable interval occurred after an initial colonization period (>21 days) and before leaves lost 50 percent of their mass. Analyses of variance showed a significant difference between sites in total insect biomass for only one (26 days) of the six emplacement intervals examined during 1987. Analyses of variance showed collector-gatherer biomass to be significantly greater at the treatment site than at the control site for all intervals of emplacement during 1987. There were no significant differences between sites in shredder biomass, and predator biomass was significantly higher on the treatment site than the control site

for only one interval (50 days). The pattern of functional group biomass during 1987 is markedly different from the 1986 pattern.

In addition to total biomass and biomass of functional feeding groups abundant individual species were also monitored. Three species of collector gatherers and a predator were examined for changes in mean dry weight per individual. All four species had a consistent pattern of change in mean dry weight from year to year.

Insect Movement Patterns. Other riverine studies have used the behavioral drift of aquatic invertebrates as a measure of community response to stressed conditions. In order to monitor for possible effects from the operation of the ELF Communications System, mark and recapture techniques are being used to discern the movement patterns of displaced dragonfly naiads.

Naiads of *Ophiogomphus colubrinus* (dragonfly) traveled downstream for short distances after their release. Lateral movements of the naiads were related to flow patterns at each of the sites. Chi-square tests of data collected over the 1985-1988 period showed significant differences between sites and years in the distance that naiads moved after release. Temporal differences are more variable than site differences. Although the variability of this parameter is high, the principal investigator feels that the distances traveled by the naiads reflect natural movement patterns and that the high variability in distribution is attributable to physical differences (i.e., river velocity, depth) between experiments. An increased number of experiments are planned for 1989.

2.10.3 Fish

An extraordinary ability to perceive EM fields has been reported for some species of fish. It is believed that fish use this perceptive ability to orient themselves and to detect prey. Fish also represent the tertiary consumers in the aquatic food chain; therefore, the characteristics of the mobile fish community, and the migratory behavior of trout in particular, are being monitored for possible effects from the operation of the ELF Communications System in Michigan.

Mobile Fish Community. Fyke nets and weirs have been deployed across the width of the Ford River drainage at five sites in or near the ELF Communications System. All fish are collected, and both community characteristics and movement through the area are recorded. Community characteristics recorded are species composition, species abundance, and biomass. In addition, the travel time of marked fish through the ELF System area, as well as the condition of abundant fish species are examined.

In 1988, the number of species collected was higher at the downstream control site than at the treatment site--the reverse of previous year. Eighteen species were collected at the treatment site and 21 at the control site. As in the past, the difference between sites in the number of species was attributed to the presence of a few rarely found species. There were no significant differences between sites in the diversity of the mobile fish community in 1988 nor over the period 1983-1988. Overall the treatment and control site continued to be similar in species composition.

Numerically, and by biomass, the mobile fish community at treatment and control sites was dominated by the same five species. In 1988, as in 1986 and 1987, the numbers of common shiners and creek chubs made up the two highest percentages of the catch; the other common species were the burbot, brook trout, and white sucker. Brook trout was the most dominant species at both sites when the community was analyzed for percent catch by biomass. Percent catch by biomass was more variable than percent catch by numbers.

The recapture frequency of marked nonsalmonid fish in 1988 was similar to that of previous years (about 11 percent). The movement of fish through the ELF Communications System area during 1986-1988 was slower than in years prior to 1986. This decline in site-to-site movements of fish was attributed to a significantly lower flow rate for the Ford River during the 1986-1988 period than that experienced during 1984 and 1985.

In order to assess for possible direct effects of the ELF Communications System on the mobile fish community, analyses were initiated in 1986 to examine the growth and condition of captured fish. The common shiner, creek chub, white sucker, and northern pike were selected as indicator species for the community. Analysis of data pooled over both sites and over the period 1983-1988, showed that common shiners and creek chubs had average to better

than average growth when compared to literature values. White suckers and northern pike displayed poor growth when compared to literature values.

In addition to growth, the condition of common shiners, creek chubs, and white suckers was examined using relative weight condition factors. As for growth, data was pooled over sites and years (1983-1988). Condition factors for creek chubs and white suckers were 4 to 20 percent below their respective species mean, while condition factors for the common shiner were above the species mean for all years examined. No statistical comparisons between sites or years for growth or condition were reported.

Brook Trout Movement. Magnetic cues have been shown to be used by fish in their migratory movements. In a thermally unstable stream such as the Ford River, it is particularly important to determine any possible disorientation of fish in their search for an optimal temperature regime.

The general pattern of trout migration has been an upstream movement in the spring to early summer, with a varied intensity and timing of peak movement from year to year. Peak catch occurred in June during 1984, 1987, 1988, in July during 1985, and with no peak apparent during 1986. Trout migrate through the ELF Communications System area (control and treatment sites) to the confluence of the Ford River and Two Mile Creek. Virtually all trout migrate up Two Mile Creek; optimal growth temperatures appear to be responsible for this movement. No downstream movement from Two Mile Creek was found for sampling periods lasting through November. Factors affecting timing of peak catches and distribution pattern appear to be water temperature, stream velocity, and trout population size.

Brook trout were found to move between the antenna ROW and Two Mile Creek at average rates of 1.4 km/day in 1984, 1.6 km/day in 1985, and 1.8 km/day in 1987. Tagged trout were not recaptured in either 1986 or 1988; and only one was recaptured in 1987. The movement rates were more variable between other possible station arrangements. Overall mean rates of 1.2 to 5.0 km/day have been determined for movement of trout through the ELF Communications System area.

Age and growth analysis indicated that the brook trout in the Ford River exhibit average or better growth than that reported in the literature. As for the nonsalmonid species, brook trout were examined using relative weight

condition factors. Brook trout from the Ford River were in average to below average condition when compared to the calculated literature average. Statistical analysis of this data is in progress, and will be reported in the 1988 Annual Report.

3. ENGINEERING SUPPORT

Many scientists agree that the relationship between EM exposure and biological response, if any, remains unresolved. Although it is unclear, several aspects of EM fields that are of potential concern include:

- intensity
- exposure duration
- intensity changes
- interaction with other fields.

Other aspects such as modulation and phasing may also be of interest. This is not to say that operation of the ELF System will cause biological effects, but only to indicate the need to document various facets of the EM fields generated by the ELF Communications System while the monitoring program is in progress.

As accurate data may be needed to evaluate cause-and-effect relationships between EM exposure and biological/ecological end points, IITRI assists university investigators by providing annual EM measurements and other EM engineering support. EM engineering support includes such activities as analysis of EM aspects of research protocols; design, fabrication, and installation of special EM exposure equipment; and review of EM aspects of investigator reports.

The following summarizes the measurement of EM field exposures at study sites, operational characteristics of the ELF System, and engineering activities carried out in support of the program during 1988. A more extensive presentation of these topics can be found elsewhere.[2]

3.1 EM FIELD MEASUREMENTS

ELF EM intensities at study sites have been measured annually since 1983 to document major changes and to characterize the temporal variability of fields. During the months of August through October 1988, measurements of 76 Hz and 60 Hz EM fields were made at all active Wisconsin and Michigan study

sites. The number of measurement points decreased from 266 in 1987 to 198 in 1988 due to the conclusion of two studies in Wisconsin.

As slime mold and wetland studies concluded data collection in 1987, EM measurements during 1988 were limited to bird study transects. In addition to historical sites, one treatment and one control transect were extensively characterized in order to document their EM variability. EM field intensities were measured along the length of both transects and across the width of the treatment transect. Because the WTF is fully operational, EM measurements were limited to 76 Hz fields. The protocol for EM measurements at Wisconsin study sites has been unchanged since 1985.

Except for two measurement points at upland flora and soil microflora sites, all 1987 measurement points in Michigan were remeasured in 1988. Nine new measurement points were added to clarify the EM exposures to biota in three studies. All 1988 EM field measurements were made during 75 ampere operation of the MTF and both 76 Hz (unmodulated) and 60 Hz EM fields were measured. Seventy-six hertz EM intensities at study sites were as anticipated. Unanticipated increases in 60 Hz field intensities at study sites near the north/south antenna element were attributed to increased currents in a transmission line west and parallel to the north/south antenna element.

3.2 TRANSMITTER OPERATIONS

In order to evaluate the effect of the operation of the ELF Communications System, investigators may need to examine EM characteristics other than intensity in their statistical analyses. This section summarizes the operational characteristics, particularly duration, of the transmitting facilities in both Wisconsin and Michigan.

Data on antenna operations have been provided to IITRI by the Navy on a minute-by-minute basis, and included all changes in operational frequency, modulation, power, and phasing for each antenna element. This information has been provided to investigators as graphical and tabular summaries and, when requested, in detailed tabular form.

The WTF has been fully operational since the last quarter of 1985. Its operating history since 1984 is summarized in Reference 2. During 1988, the WTF transmitted modulated 76 Hz signals for approximately 8500 hours (about 96 percent of the total available time). The approximately 5 percent of nonoperational time represented scheduled weekly maintenance periods and unscheduled repairs. The north-south and east-west antenna elements were operated simultaneously at 300 amperes for more than 99 percent of the transmission time.

The MTF has been intermittently operated at less than full power since March 1985. The operational history of the MTF is also summarized in Reference 2. In 1988, the MTF was operated for about 1000 hours (about 12 percent of the total available time) with north-south and east-west elements operated separately. On working days, transmitter operations were conducted according to a 15-minute cycle, as follows:

- 5 minutes; both elements off
- 5 minutes; only north-south element energized
- 5 minutes; only east-west elements energized.

The operational time was evenly split between the north-south and both east-west antenna elements. The elements were intermittently energized at a 15 ampere current from January througn June 1988 and at a 75 ampere current for the remainder of the year. About 41 percent of the total operational time was at 15 amperes, while 59 percent of the operational time was at 75 amperes.

3.3 OTHER SUPPORT ACTIVITIES

Soil amoeba studies employ culture chambers that isolate the amoeba from the surrounding soil. As there is a mismatch between the conductivity of the soil and culture media, IITRI-designed control circuitry has been used to match voltages and currents supplied to the culture from collecting electrodes to similar parameters present in the soil.

The intensity of both 76 Hz and 60 Hz earth electric fields varys with seasonal changes in soil conductivity. In addition, 60 Hz electric fields in soil vary with changes in the current flowing in nearby transmission and distribution lines. Therefore, measurement of EM fields once a year may not adequately represent the electric field exposure of the frequently subcultured

amoebae. During 1988, IITRI installed microprocessor-controlled data loggers at amoeba study sites. The loggers recorded the earth electric field, as well as electrical parameters within the chamber. At the end of the season, the electrical parameters were used to calculate the electric field and current density within the chamber for the term of the experiment. Earth electric field data were also collected throughout the winter, in order to determine the seasonal variability of this aspect.

Researchers have found that in 1987 and 1988, displaced birds took significantly longer to return to control sites than to treatment sites. There was no significant difference between birds captured at treatment and control sites in 1986. In addition to annual EM measurements at capture sites and release points, IITRI was asked to provide an EM characterization for the paths of return. IITRI provided copies of geomagnetic maps, as well as maps plotting return paths relative to power distribution systems. The return path to the control site was flown in a small plane in an attempt to identify all sources of EM fields. Other than two existing transmission lines from local hydroelectric generators, no EM field sources were found. Information on the power outputs of the plants and transmission lines were obtained and provided to the investigators. Preliminary examination of the data does not indicate an EM basis for the difference between transects in the return time of the birds.

In 1987, IITRI performed EM measurements and analyses of voltages induced onto ambient monitoring equipment used by the upland flora and soil microflora studies from adjacent MTF antenna elements. A design for mitigation of induced voltages and lightning protection was completed and implemented during 1988.

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APPENDIX A

ECOLOGICAL MONITORING PROGRAM: LIST OF PUBLICATIONS/PRESENTATIONS, 1982-1988

ECOLOGICAL MONITORING PROGRAM:
LIST OF PUBLICATIONS/PRESENTATIONS, 1982-1988

Upland Flora (Michigan Technological University)

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APPENDIX B

ECOLOGICAL MONITORING PROGRAM:
FY 1988 RESOURCES

ECOLOGICAL MONITORING PROGRAM:
FY 1988 RESOURCES

The Navy has been committed to a program of long-term ecological monitoring since the ELF Communications System site selection process was initiated. The Ecological Monitoring Program is identified separately from other environmental protection work for future year budgeting purposes; therefore, continuity of the Program is anticipated, presuming continued Congressional approval and funding of the ELF Communications System.

During 1988, monitoring studies were conducted under 10 subcontracting agreements between IITRI and study teams from five universities (see Table B-1). IITRI provides engineering support and overall program management. Each study team is headed by a principal investigator with academic training to the doctoral level. Most of the staff also have advanced degrees, with expertise and publications in the areas under study. During 1988, the Ecological Monitoring Program consisted of more than 100 people expending a total of about 100,000 staff hours.

TABLE B-1. ECOLOGICAL MONITORING PROGRAM: FY 1988

Study	Subcontractor	Principal Investigator(s) (Total Staff)	Professional and Staff Hours 1988
Upland Flora	Department of Forestry Michigan Technological University	G. D. Mroz, Ph.D. (18 persons)	14,783
Soil Microflora	Department of Forestry Michigan Technological University	J. N. Bruhn, Ph.D. (7 persons)	5,013
Slime Mold	Biomedical Research Institute University of Wisconsin (Parkside)	E. M. Goodman, Ph.D. (6 persons)	1,729
Soil Amoebae	Department of Zoology Michigan State University	R. N. Band, Ph.D. (6 persons)	6,747
Soil Arthropods and Earthworms	Department of Zoology Michigan State University	R. J. Snider, Ph.D. R. M. Snider, Ph.D. (15 persons)	17,143
Native Bees	Department of Entomology Michigan State University	K. Strickler, Ph.D. M. Scriber, Ph.D. (10 persons)	7,071
Small Mammals and Nesting Birds	Department of Zoology Michigan State University	D. L. Beaver, Ph.D. (10 persons)	13,611
Bird Species and Communities	Natural Resources Institute University of Minnesota (Duluth)	G. J. Niemi, Ph.D. J. M. Hanowski (9 persons)	6,720
Wetland Flora	Department of Botany University of Wisconsin (Milwaukee)	F. Stearns, Ph.D. (5 persons)	4,791
Aquatic Biota	Departments of Zoology, Entomology, Fisheries and Wildlife Michigan State University	T. M. Burton, Ph.D. R. J. Stout, Ph.D. W. W. Taylor, Ph.D. (15 persons)	15,766
Program Integration and Engineering Support	Electromagnetics and Electronics Department IIT Research Institute	J. E. Zapotosky, Ph.D. (4 persons)	5,200
		TOTAL	99,574